Study of Revolutionary Architectures for Atmospheric Chemistry, Earth Radiation Balance, and Geomagnetism Observations

Summary of the Science Workshop

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1 Introduction

1.1 RASC Effort Overview

The key objectives of the Revolutionary Aerospace Systems Concepts (RASC) Program are to develop aerospace systems concepts and technology requirements to enable future NASA missions. The RASC Program will apply a "top-down" perspective to explore new mission capabilities and discover "What's possible".

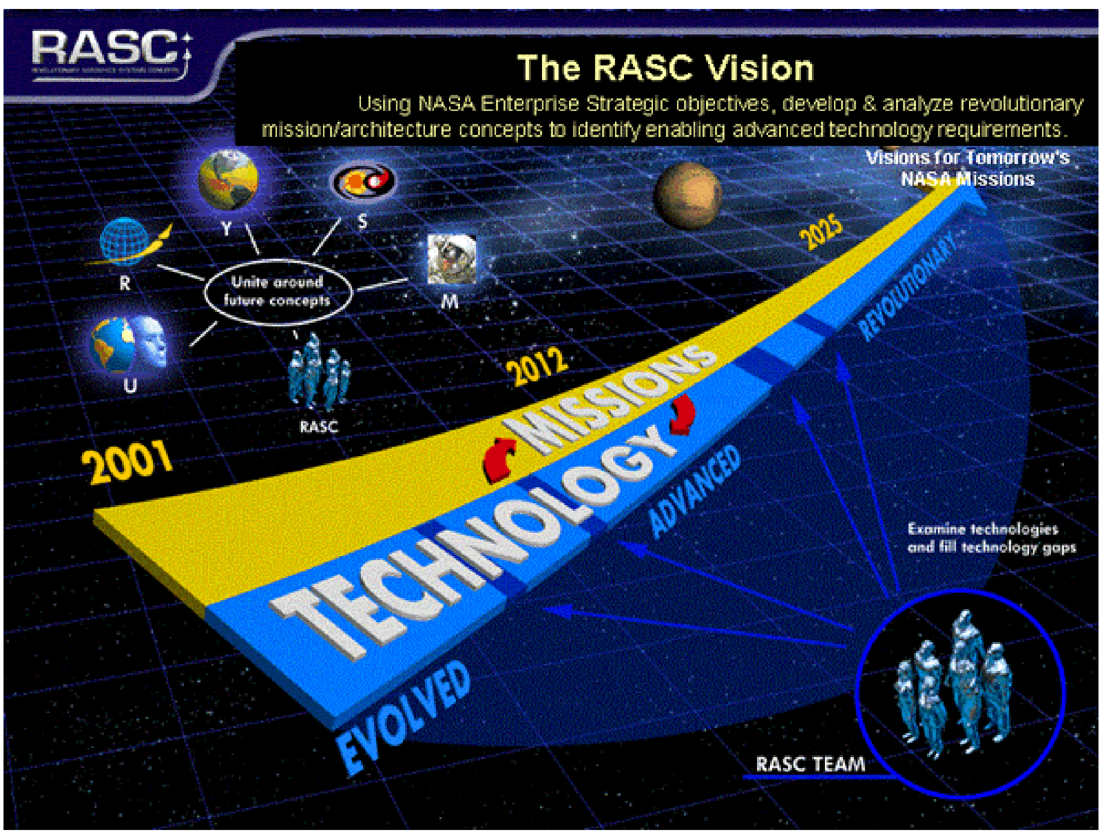


Figure 1 The RASC Vision

By accomplishing this objective, NASA will provide the concepts and technologies that can make it possible to go anywhere, at anytime, safely, reliably, and affordably. The RASC Program is focused on making significant strides in accomplishing NASA's strategic goals for science, exploration, and commercialization. The RASC Program seeks to maximize the benefits of revolutionary capabilities that span across Enterprises as it defines the technology requirements and the performance criteria to meet these challenges. The RASC Program is exploring space concepts, aeronautical concepts, and concepts that blur the line between aeronautics and space. The RASC Program will look beyond the next step in aerospace development and towards the next age of aerospace technology.

One area where revolutionary concepts are desired is stratospheric platforms from which *in-situ* and remote Earth science measurements can be made. NASA contracted Global Aerospace Corporation to lead a small study to evaluate the capabilities of the candidate platforms to meet NASA Earth Science objectives. The science areas where these platforms are expected to make significant impact include Atmospheric Chemistry, Earth Radiation Balance, and Geomagnetism. Potential platforms include Ultra-Long Duration Balloons (ULDBs), other balloon concepts, airships, Uninhabited Air Vehicles (UAVs), and crewed aircraft.

1.2 Purpose of this Report

The purpose of this report is to summarize the results of the workshop, to summarize science applications and requirements suggested at the workshop, and to identify performance requirements for stratospheric platforms based on these applications and science requirements.

1.3 Organization of this Report

The remainder of the report is organized in the following way. In Section 2 we give an overview of the workshop organization and give the list of participants. Section 3 describes potential mission concepts developed during the workshop, their relationship to NASA's goals, and measurement and instrument technology requirements for these concepts. Section 4 summarizes the results of the workshop.

2 Science Workshop Summary

To obtain the users input on potential science applications and requirements for the proposed long-duration stratospheric observing platforms, GAC hosted an Earth Science workshop at Marriott Courtyard, Greenbelt, MD, on June 19, 2002. 22 prominent scientists from NASA Goddard Space Flight Center (GSFC), NASA Langley Research Center (LaRC), US geological Survey (USGS), NOAA, University of Maryland, John Hopkins University, Colorado State University, State University of New York (SUNY) and from IZMIRAN, Russia attended the workshop. Chuck Williams and John Oberright (GSFC/WFF), and Matthew Heun, Alexey Pankine, and Kerry Nock (GAC) attended plenary and group sessions. Kerry Nock, Matt Heun and Alexey Pankine organized the sessions and gave scientists their charter for the meeting. The picture below shows the workshop attendees.

Figure 2 Workshop Attendees

Prior to the workshop, the Earth Science Working Group (ESWG) that included experts from each of the three science areas in the study title (i.e. Atmospheric Chemistry, Earth Radiation Balance, and Geomagnetism) was formed. The group leads of the ESWG are: William Heaps (Atmospheric Chemistry group chair), Michael Purucker (Geomagnetism group chair), Zhanqing Li (Earth Radiation Balance group chair) and Albert Arking (Earth Radiation Balance group co-chair). The ESWG is charged with the task of developing science requirements in their area of expertise for in-situ measurements from a stratospheric platform with the following capabilities:

- 30- to 35-km constant altitude
- 100-day flights (eventually 365 days)
- 1 kW of power
- 200 kg or more payload capacity
- payload recovery at end of flight.

The workshop participants were invited to the workshop based on the recommendations of the members of the ESWG to assist in the developing of the science requirements. The participants were:

Geomagnetism Group (Michael Purucker, GSFC)

Yury Tsvetkov, IZMIRAN (Research Institute of the Earth's Magnetism, Ionosphere, and Radiowave Propagation, Russian Academy of Science) Russia

Jim Heirtzler, GSFC

Gunther Kletetschka, GSFC

Patrick T Taylor, GSFC

Dimitar Ouzounov, GSFC

Jeff Love, USGS (Denver)

Benoit Langlais, GSFC

Katherine Nazarova, GSFC

Earth Radiation Balance Group (Zhanqing Li, UMD and Albert Arking, JHU)

Wenying Su, NASA/LaRC

Ellsworth Dutton, NOAA (Boulder)

Rachel Pinker, UMD

Seiji Kato, NASA LaRC

Dave Atlas, GSFC

Jim Spinhirne, GSFC

Lee Harrison, SUNY

Thomas Vonder Haar, Colorado State University

Warren Wiscombe, GSFC

Atmospheric Chemistry Group (William Heaps, GSFC)

Elliot Weinstock, Harvard University

During the meeting, GAC presented an outline of the meeting and the context of the RASC effort (see Appendix A). GAC then presented an overview of stratospheric platforms and their capabilities (see Appendix B). This briefing was followed by Dr. Pankine who charged the science group with the task of generating the science requirements and provided the group with a process for developing them (See Appendix C). (We note at this point that the *science requirements* that need to be developed are rather *platform performance requirements* that make the underlying science possible. Many of these requirements are technological in nature. To avoid confusion, we will call them the platforms performance requirements henceforth.) The rationale behind performance requirements development is illustrated on Figure 3. First, the scientists were asked to identify key Earth science questions that need to be answered in the next

25 years. The scientist could pose their own questions or use the key questions outlined in the NASA Earth Science Enterprise (ESE) Strategic Plan (See Appendix D). They were then asked to discuss potential mission scenarios and applications utilizing the stated capabilities of future stratospheric platforms that would help to answer those key questions. The scientists were asked to describe the measurements and instrumental approaches for these missions and applications, and to outline the performance requirements that these measurements and instrumental approaches impose on the observational platform. The sets of requirements developed in this way were recorded in the Data Capture Questionnaires (DCQs) developed for this purpose (see also Appendix D for a sample DCQ and Appendix E for the actual DCQs filled at the workshop). The performance requirements distilled from the DCQs will drive the candidate stratospheric platform evaluation process.

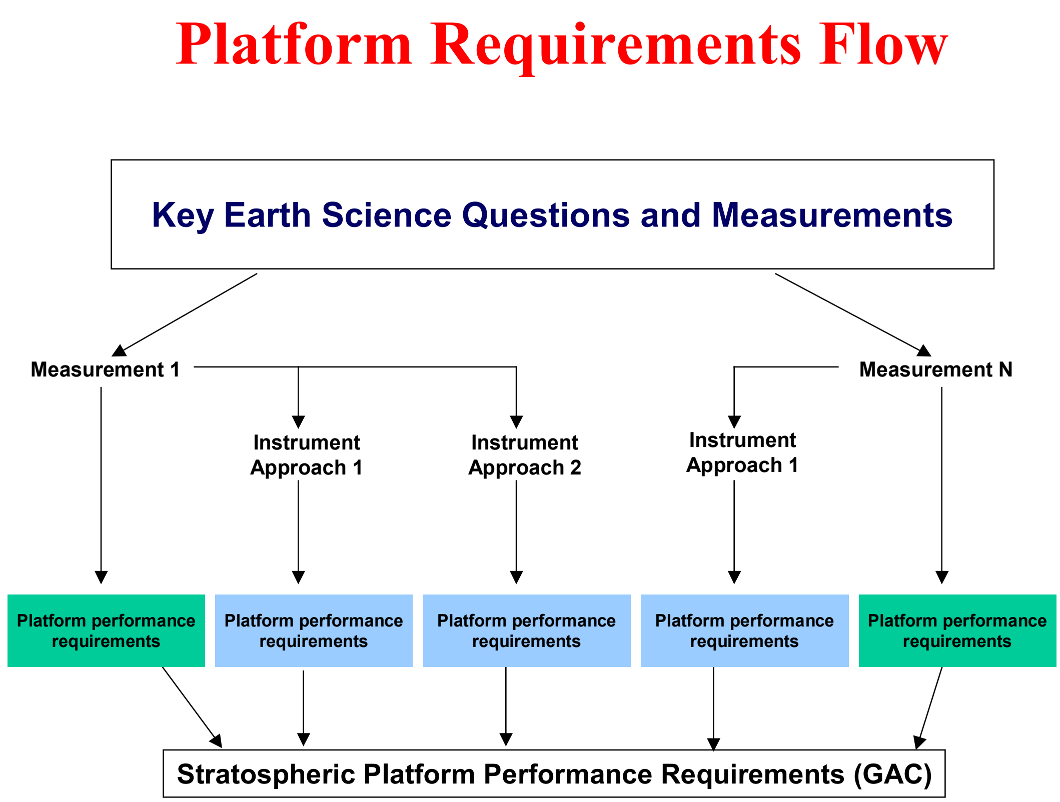


Figure 3 Rationale Behind Science Requirements Development

After Dr. Pankine's charge to the group, the attendees broke into three subgroups to discuss requirements for future science missions. The following section describes the potential missions and requirements developed by the scientists in each group.

3 Potential Mission Scenarios, Approaches and Requirements

This section summarizes the science requirements input received from the scientists during the workshop and during the follow up process.

3.1 Geomagnetism

The Geomagnetism group formulated the following questions to be addressed by observations from the future stratospheric platforms:

G1. What is the nature of the middle and lower crust?

G2. How is the South Atlantic magnetic anomaly changing?

G3. What is the sub-ice circulation in Polar Regions?

G4. What are the magnetic signatures associated with natural hazards (crustal deformation and faulting, for example)?

G5. What are the stratospheric/atmospheric processes with magnetic signatures?

The advantages of using the stratospheric platforms are:

- Observations at stratospheric altitudes allow the separation of various components of Earth's magnetic field
- It allows for the addition of intermediate spatial wavelength information to existing surface and satellite surveys
- Long term coverage over hard to access sites
- Space weather events warnings for polar satellites.

Due to time constraints of a one-day workshop the group participants voted to consider only two questions from the list above in more detail, namely, questions G1 and G2.

More information on geomagnetism from stratospheric platforms can be found at http://core2.gsfc.nasa.gov/research/mag_field/purucker/huang/index1.html

The following sections describe the measurements, instrument approaches and mission scenarios corresponding to these two questions posed above.

G1 What is the nature of the middle and lower crust?

Based on seismic data the Earth's interior is partitioned into a core, mantle and crust (see cutaway view of the Earth on Figure 4, picturing the crust, mantle, liquid outer core, and solid inner core). The crust is the outermost part of the solid Earth and is approximately 30 km thick. The structure of the crust needs to be studied to understand the geological processes (like plate tectonics) that shape the surface of the Earth.

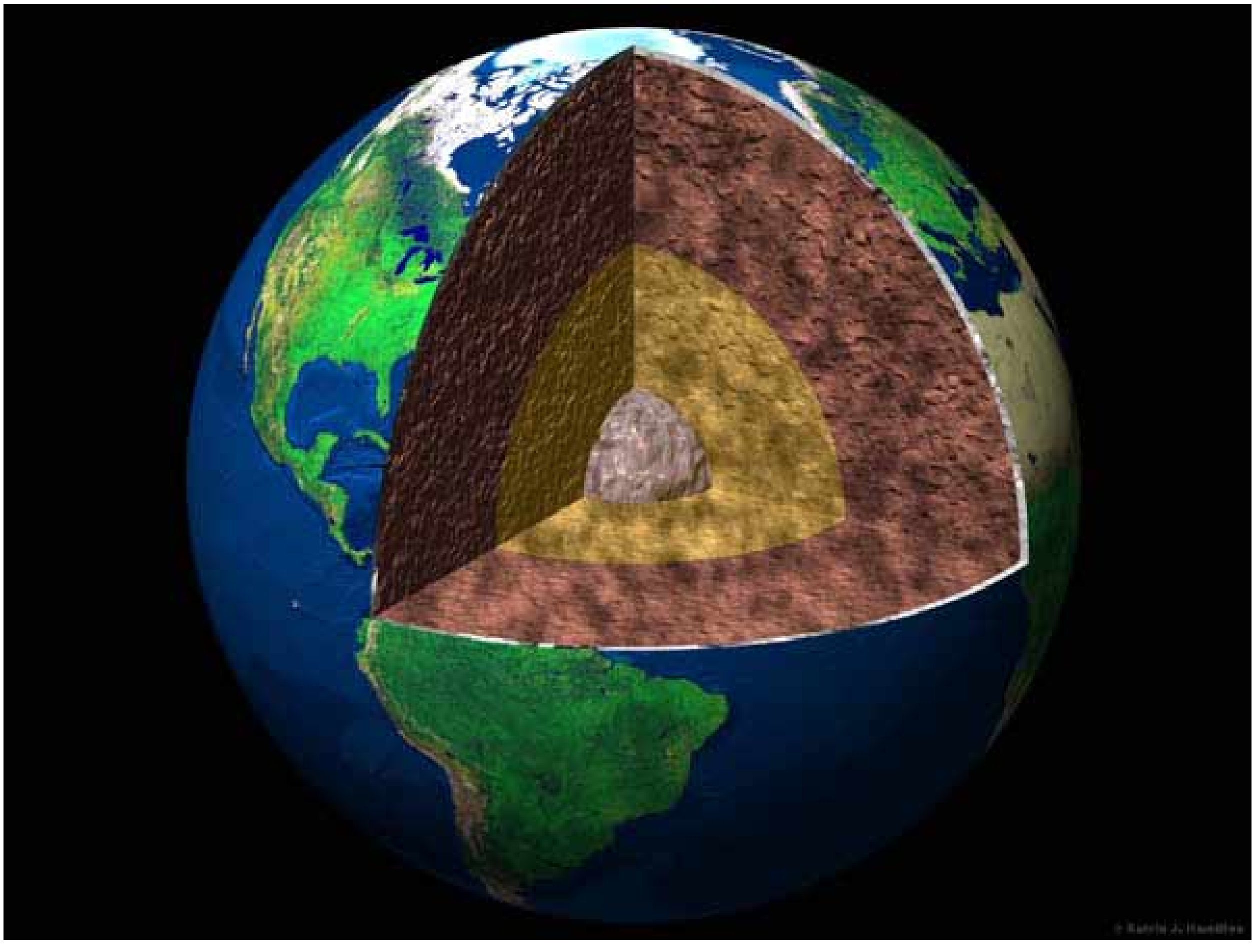


Figure 4 Cutaway view of the Earth (image copyright Calvin J. Hamilton, http://www.solarviews.com).

One of the ways to study the crustal structure is by measuring the Earth's magnetic field. Structure, depth to magnetic source, location of source, magnetization directions, and conductivity distribution could be deduced from these measurements. Measuring the Earth's magnetic field from stratospheric platforms offer several advantages over surface, aircraft, and satellite measurements.

Even though surface measurements are made around the world by magnetic observatories, they only cover a small fraction of the Earth's surface. Systematic observations are lacking over oceans, Antarctica, Africa, South America, Siberia and other places. Aircraft observations lack sufficient range, cannot provide global coverage and are relatively expensive. Measurements from oceanic vessels are slow and expensive. Satellite measurements are affected by ionospheric and magnetospheric disturbances and require very high instrument sensitivity due to the weak field at orbital altitudes (the decrease of magnetic field with distance is inversely proportional to the cube of the distance). The high orbital speed of the satellites also reduces the resolution of the measurements. Long duration stratospheric platforms would be able to make systematic measurements over hard to reach places over long periods of time.

Measurements from stratospheric heights would also allow the addition of intermediate wavelength information to the existing surface and satellite surveys. Because the stratospheric altitudes (30-35 km) are comparable to the thickness of the crust (30 km) the whole depth of the crust can be “seen” from these altitudes. While it is beneficial to be closer to the magnetic source (i.e., closer to the surface), “patching” together the surface and satellite surveys calls for higher stratospheric altitudes.

In addition, some magnetic field observations are only possible from stratospheric altitudes. For example, vertical gradient measurements of the magnetic field from the stratospheric altitudes are currently the most reliable method of separating the external and internal components of the Earth’s magnetic field and for measuring crustal magnetic anomalies.

Systematic observations are required globally to distinguish magnetic field variations over various spatial and temporal scales, and to separate the effects of the components of the magnetic field. Gradient measurements require simultaneous measurements with 2 km vertical or horizontal resolution to infer magnetization and conductivity distributions. Vertical gradient measurements seem to be more valuable, because the spectrum of such measurements is the same as the spectrum of the field. Vertical gradient measurement can measure magnetic signal from a very deep source, which cannot be done with a horizontal gradient measurement. Gradient measurements are done simultaneously by spatially separated instruments. Depending on a platform capability, this may require one or more platforms.

The instrument “footprint” on the surface for magnetic field measurements is of the order of the instrument altitude. To provide complete coverage for a stratospheric survey the platform ground tracks would need to be separated by no more then 35 km to provide overlap between surface instrument footprints.

Scalar (proton) and vector (flux gate) magnetometers can be employed for magnetic field surveys. The scalar instrument measures the total value of the magnetic field at a particular point in space. It does not give information about the direction of the magnetic field vector, which fully characterizes the magnetic field. The scalar magnetometer is sufficient for a magnetization distribution survey. The instrument is relatively cheap, so that post-flight recovery efforts are not justified. Scalar magnetometer is a light (1 to 2 kg) instrument drawing 1 W of power. Measurements are usually taken at a frequency of 1 per minute. This frequency is adequate for the proposed magnetic survey application. A higher sampling frequency of 1 Hz is easily achievable, if necessary, to look for high frequency field variations. However, it is not clear at the moment if such high frequency measurements are needed. There are no requirements on the instrument or platform attitude control or knowledge, since only the total field is measured. The instrument, however, should not rotate faster than one rotation per minute.

Another approach may employ a vector instrument. Such an instrument would be required for conductivity distribution survey. A vector magnetometer with associated star camera is a relatively expensive instrument package and needs to be recovered after flight termination. It is relatively heavy (5-10 kg) and draws 2 to 3 W of power. Vector measurements have very stringent requirements on the instrument (and platform) attitude knowledge: the attitude must be known to better than 3 arc seconds. The instrument would be calibrated on the ground before the flight.

A third type of magnetometer may be implemented in the future. It is the self-calibrating scalar-vector helium magnetometer currently being developed by the NASA Instrument Incubator Program (IIP).

The tables below summarize the performance requirements:

Table 1 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Global or regional
Desired horizontal resolution within the coverage region	35 km for survey; 2 km for gradient meas.
Desired vertical coverage	From 30-35 km
Desired vertical resolution	2 km for gradient meas.
Spatial accuracy	5 km for survey
Temporal characteristics of the measurement:	
Flight duration	N/A
Frequency of observations during the flight	1/min
Simultaneity with other observations	Yes, with other platforms or instruments for gradient meas.
Other:	
	N/A

Table 2 Platform performance requirements dictated by the Instrument Approach (Scalar (S) or Vector (V) magnetometers):

Safe payload recovery	Yes (V) No (S)
Useful science payload mass	5-10 kg (V) 1-2 kg (S)
Power draw	2-3 W (V) 1 W (S)
Pointing accuracy, including: Platform	3 arc sec attitude knowledge (V) None (S)

attitude control; Platform attitude knowledge.	Rate of rotation slower than 1/min (V, S)
Position accuracy, including: Platform position control; Platform position knowledge.	GPS position knowledge (V, S)
Calibration	On the ground before flight
Data storage and relay	Small
Coordination between platforms	Possible coordination for gradient meas.
Other	N/A

G2 How is the South Atlantic magnetic anomaly changing?

The South Atlantic Anomaly (SAA) is an oval-shaped geographic region centered roughly off the east coast of Brazil where the Earth's geomagnetic field is relatively weak at all altitudes.

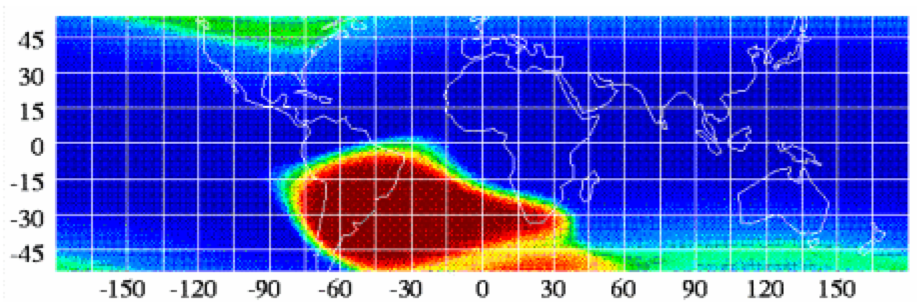


Figure 5 Relative location of the SAA based on data from South Atlantic Anomaly Detector (SAAD) aboard the ROSAT spacecraft (Courtesy of NASA).

The weakness of the geomagnetic field in the SAA affects the Van Allen radiation belts that surround the Earth. Although the inner surface of the Van Allen radiation belts is at the height of 1200-1300 km from the Earth's surface, over the SAA it deep down to 200-800 km. Earth-orbiting spacecraft enter the Van Allen radiation belts over the SAA and are subjected to strong radiation and heavy bombardment by energetic particles (protons and electrons) "stored" there. This causes problems with onboard electronic equipment and sometimes can permanently disable a spacecraft. The intensities of energetic particles fluxes over SAA are show on Figure 5 (red color represents the highest intensity and blue – the lowest).

A stratospheric platform positioned above the SAA could serve as an observatory monitoring the changes within the SAA and in the space environment above it. Solar flares create variations in the near Earth space environment producing "space weather" that can be harmful to satellites. The stratospheric space weather observatory would provide timely warning for polar-orbiting satellites and deepen our understanding of the physics of geomagnetic field decrease. In the long term (over decades) the platform would allow to study the influence of the solar activity and radiation on climate, monitor solar storms (that do not happen every year) and monitor the core processes responsible for the observed main field weakening and shift of the SAA towards Africa.

A single platform over the SAA would be sufficient. Another platform can be positioned over the North Pole, which also presents a good vantage point for observations of the space weather and would provide data for comparison with the existing South Pole magnetic observatory.

The advantages of the stratospheric platforms over other approaches are in that it is impractical to place a magnetic observatory on ice (North Pole); space weather observations must be made from altitudes as close as possible to affected satellites; low altitude satellites are not able to make temporal measurements of local radiation environment.

The platforms would carry scalar and vector magnetometers and, probably, electric field and particle instruments to fully characterize potential spacecraft hazards. The requirements for magnetometers are the same as in Section G1, except for the higher frequency of the observations - 20 Hz, - that is needed to observe the very dynamic phenomenon of the space weather. The attitude knowledge requirements is to know the instrument attitude to better than 20 arc seconds.

The observatories would need to remain above the study area. However, for space weather monitoring, some wandering around may be allowed, “to find” a better monitoring place.

The space weather data would need to be downlinked in real time to alert spacecraft.

The tables below summarize the performance requirements:

Table 3 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Over SAA, North Pole
Desired horizontal resolution within the coverage region	N/A
Desired vertical coverage	From highest possible altitude
Desired vertical resolution	N/A
Spatial accuracy	N/A
Temporal characteristics of the measurement:	
Flight duration	1 year or more
Frequency of observations during the flight	20 Hz
Simultaneity with other observations	Simultaneous with South pole observations
Other:	
	N/A

Table 4 Platform performance requirements dictated by the Instrument Approach (Scalar (S) or Vector (V) magnetometers):

Safe payload recovery	Yes (V) No (S)
Useful science payload mass	5-10 kg (V) 1-2 kg (S)
Power draw	2-3 W (V) 1 W (S)
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	20 arc sec attitude knowledge (V) None (S) Rate of rotation slower than 1/min (V, S)
Position accuracy, including: Platform position control; Platform position knowledge.	GPS position knowledge (V, S)
Calibration	On the ground before flight
Data storage and relay	Real time relay
Coordination between platforms	Possible coordination for gradient meas.
Other	N/A

3.2 Earth Radiation Balance

The Earth Radiation Balance (ERB) group discussed a number of questions to be addressed by observations from the future stratospheric platforms that can be grouped into two categories: those dealing with climate scales and those dealing with synoptic scales. In the climate scale category the basic question is:

ERB1 How can we determine the biases in the existing satellite system for monitoring ERB?

The questions in the next category constitute the next level of detail dealing with synoptic scales. Their quest is to understand how the fluxes respond to changes in the atmosphere below, including changes in temperature, humidity, and cloud cover, changes in the stratosphere due to volcanic eruptions, sudden warming, etc. The aim here is to improve our ability to model the flux:

ERB2 What are the dynamics and small-scale structure of the Earth radiation balance? How does ERB evolve over lifetime of a cloud or a large system?

ERB3 What is the relationship between the atmospheric temperature, moisture, clouds and aerosols and the radiation budget at top and bottom of the atmosphere? What is the interaction of ERB with hydrological cycle in some poorly understood regimes, such as ERB drift in the tropics and stratospheric H_2O decrease?

ERB4 How well can we model the ERB at top-of-atmosphere (TOA) and surface (including spectral and angular variations) given vertical profile information?

ERB5 What are regional and far-reaching impacts of stratospheric natural events (i.e. volcanic eruptions; sudden warmings; tropopause breaks; etc.) on climate?

These questions fall into the following general scientific themes:

- Climate forcing (trace gases, aerosol, cloud, land cover change, etc.)
- Upper boundary problem (radiation balance)
- Cloud parameterizations (sub-scale variability, temporal variability, cloud system evolution, etc.)
- Changes in stratosphere (H_2O, O_3, …)
- Monitoring special events (hurricanes, volcanoes, etc).

The advantages of using the stratospheric platforms are:

- No radiance to flux conversion (satellites only measure radiance)
- In-situ satellite validation
- Temporal coverage not possible from satellites
- 100 day platforms around the globe would measure flux directly and provide dynamics
- Continuous operation at fixed locations
- Capability of large payloads (relative to satellites)
- Synergetic observations of multiple instruments
- Complementary to ground-based observations: provide upper-boundary and profile information

The group formulated the following mission that would address the questions above:

- To deploy a suite of instruments at fixed and drifting locations above the Earth in some climatologically important regions;
- To collect a well-defined time series of atmospheric radiative transport data;
- To make observations on the scale of a General Circulation Model (GCM) grid box, so as to define the physics underlying some of the important parameterizations in the GCM's used in climate change.

The variables that are required to observe are:

- TOA and surface radiative irradiance and radiance (broadband & spectral);

- atmospheric flux divergence;
- profiles of atmospheric species (T, P, u, v, h, O_3);
- profiles of radiative active agents (water vapor, aerosol, cloud);
- surface properties (albedo, emissivity).

The suggested instruments for these measurements are:

- broad-band and narrow-band radiometers (solar and infrared radiation); wide-field-of-view (WFV) and scanning instruments, CCD imagers.
- cloud profile radar (for cloud properties measurements), suggested frequencies are 35 and 95 GHz;
- Lidar (pulsed laser; particle and thin cloud properties measurements);
- sky imagers (for cloud cover measurements)
- microwave radiometer (for water vapor and liquid water measurements)
- unmanned drones and radiosondes (for temperature, humidity and winds measurements).

The following sections describe the measurements and instrument approaches in more detail.

ERB1 Radiation flux at TOA.

The Earth's climate system is driven by the distribution of incoming energy from the sun and the outgoing energy escaping to space. The earth radiation balance (ERB) is constantly changing due to natural and anthropogenic changes on regional and global scales, such as clouds, jet contrails, the surface, and the atmosphere. The measurement of the solar radiant flux reflected from and the terrestrial radiant flux emitted by the earth-atmosphere system is an integral part of NASA's Earth Science Enterprise program. A new set of Earth radiation balance data is now being provided by the NASA CERES (Clouds and the Earth's Radiant Energy System) instrument on the Tropical Rainfall Measuring Mission (TRMM), by the Terra satellite mission that began in March 2000 and is expected to continue through 2007, and also by the newly launched Aqua satellite. Figure 6 shows an example of data being returned by Terra CERES instrument. The image shows monthly averaged thermal (LW) radiation emitted to space from Earth's surface and atmosphere (left sphere) and sunlight (SW radiation) reflected back to space by the ocean, land, aerosols, and clouds (right sphere) for the month of April, 2001. The LW flux varies from about 100 W/m^2 (light-blue) to 350 W/m^2 (yellow). SW flux varies from 0 W/m^2 (blue) to about 400 W/m^2 (light-green) (Data courtesy Bruce Wielicki and Takmeng Wong, and the CERES Science Team at NASA Langley Research Center; Images courtesy Tom Bridgman, NASA GSFC Scientific Visualization Studio).

The ERB measurements on these missions assist the development and testing of our ability to predict long-term climate variability, seasonal-to-interannual changes on the local-to-global scales, and the effects of natural disasters such as major floods, biomass burning, and volcanic eruptions.

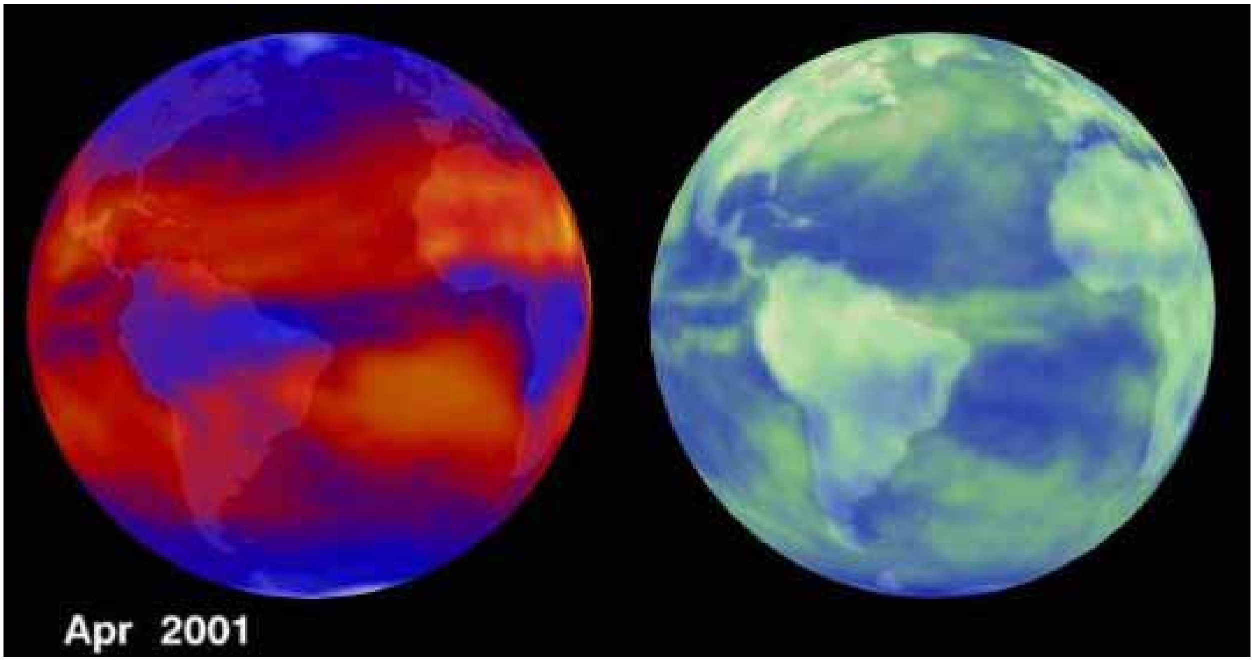


Figure 6 LW and SW fluxes measured by CERES.

A weakness of all space-based radiometric instruments is that they are calibrated in terms of the radiance ($W/m^2/sr$). The radiance data returned from space must then be converted from radiance at orbital altitude to flux (W/m^2) at the TOA. This is accomplished using the earth-satellite geometry along with angular directionality models (ADMs) to account for the directionality of thermal radiation emitted and sunlight reflected from the earth-atmosphere system. Integration of the net flux (incoming minus outgoing) over the area of an imaginary sphere defined by the TOA then yields the earth radiant energy budget (W). Integration of the net flux over a spherical sector of this imaginary sphere yields the regional earth radiant energy budget. In most ERB satellite missions such as CERES, the radiance-to-flux conversion process is the principal source of uncertainty in instantaneous fluxes estimated from radiance measurements. It introduces a 4-percent averaged uncertainty in the flux estimation (instantaneous error can be up to 100%).

An advantageous location from which to measure the ERB is the TOA, where in-situ measurements can be utilized directly. Stratospheric platforms offer the possibility of positioning a flux-measuring instrument at the TOA, thereby measuring the desired flux directly and so obviating the need for ADMs and their attendant uncertainty. Stratospheric platforms can be used to validate satellite measurements or to do independent observations.

Direct flux measurements from a stratospheric platform will be a very valuable validation dataset for satellite ERB measurements, because they eliminate all the assumptions needed in remote sensing. Since the calibration uncertainty of the satellite instrumentation itself is better than 1 percent, we expect the direct measurements can provide more accurate flux products if we move those instruments to 35 km. The non-science cost of the low-cost high-altitude platforms could be much lower than that of satellite missions.

For a platform at 35 km, the spatial resolution of the flux measurement is on the order of 700 km. Satellite data produced by ADM have a spatial resolution of about 100 km. 100-day long stratospheric platform mission would provide opportunity to validate flux products generated using ADMs for CERES. More important, 100-day operations offer an opportunity to study seasonal variations.

In addition, fluxes measured from a constellation of platforms do not have diurnal bias because all times of day are sampled. They also do not have sun-angle bias. Slow-moving stratospheric platforms (approximately 1-percent as fast as satellites) can observe the dynamics of terrestrial and solar radiation. From sunrise to sunset, a stratospheric platform could capture the diurnal variations of the TOA fluxes over particular area. A constellation of platforms would be able to monitor dynamic changes in LW and SW fluxes over the entire globe. This would provide unprecedented data to study short time scale phenomena in a continuous and global observation context.

One can start with a single platform to test the whole system. The horizontal coverage of these measurements would be of the order of 1000 by 1000 km, with the resolution of 50 to 100 km. The horizontal resolution is the distance between the successive measurements. It may be equal to the dimensions of the radiometer footprint. The flight duration could be 10 days. This application would be very useful for supporting satellite validation.

One then could move to regional coverage, with a small constellation (3-5 platforms) participating in a field mission to provide the TOA fluxes for radiation closure measurement or satellite retrieval validation purposes. Regional coverage by stratospheric platforms can also be used to trace the severe weather system, such as thunderstorm and squall. The horizontal resolution would be of the order of 100 to 200 km with the flight duration from 6 month to a year. This would become a most useful tool to assist some field programs such as the Atmospheric Radiation Measurement (ARM) of the Department of Energy.

Eventually one would hope to have a large constellation to measure the ERB globally. The measurement resolution would be of the order of 200 to 500 km with the flight duration from 5 to 10 years.

In all cases the measurements would be done continuously with averaging window of 1 minute. The measurements would also be adaptive, meaning that the platforms would be directed and repositioned to observe specific phenomena or regions. Angular distribution and spectral flux measurements, vertical atmospheric profiles and surface properties measurements would need to be done simultaneously with the total flux measurements. Atmospheric and surface properties would be done over longer – synoptic – timescales, than the flux measurements, because they are not expected to very significantly over short timescales. These simultaneous measurements are described in the following sections (ERB2-ERB5).

The flux measurements could be done with the active cavity radiometer (ACR) that would provide wide field-of-view broadband flux measurements, scanning spectral radiometer for angular and spectral distribution and a broadband radiometer (scanning or an array of instruments) for angular distribution of broadband radiance. The spectral instrument is needed (as well as broadband instruments) to balance the radiation budget spectrally, rather than just broadband.

ACR instrument weighs 5 kg and draws 5 W of power. Single ACR instrument may require a moveable filter to do both the SW and the total flux measurements, or multiple instruments with unmovable filters may be used. Pointing knowledge may be required depending on the desired measurement resolution (hemispheric versus limited field of view). Some pointing control may be required to keep the instrument pointing roughly towards nadir.

Spectral measurements could be done with moderate resolution (50 wave numbers in 300 nm to 2000 nm band) scanning spectrometer. Higher resolution in this domain is not practical, however, higher resolution in selected narrower domains would be practical in future. 100 angular non-overlapping measurements are required in a hemispheric scan (2π steradians). Scanning spectrometer weighs 100 kg today, which can be reduced to 25 kg at a higher production cost. The instrument draws 100 W of power during a day, and 10 W in a sleep mode during night (only shortwave channel would go into sleep mode at night). The pointing knowledge of the nadir angle is required to better than 0.1 degrees and knowledge of the azimuthal angle is required to within 10% of the instrument field-of-view, which corresponds to about 4˚. The required pointing control accuracy must be comparable to the pointing knowledge accuracy.

Broadband instrument weighs 25 kg, and draws 50-100 W of power.

Platform positions would need to be known with the GPS accuracy. Platform positioning control with accuracy better than 10 km would be required for regional horizontal array of platforms. Platform positioning control with accuracy better than 1 km would be required for site overflight. Free drifting constellations of platforms would require maintaining some (large) separation distance between the platforms.

Recovery is required for all instruments. All instruments would be calibrated post-flight.

The tables below summarize the performance requirements:

Table 5 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	a) 1000 by 1000 km – single platform b) Regional – 3-5 platforms c) Global
Desired horizontal resolution within the coverage region	a) 50 to 100 km b) 100 to 200 km c) 200-500 km
Desired vertical coverage	From TOA

Desired vertical resolution	N/A
Spatial accuracy	GPS accuracy OK
Temporal characteristics of the measurement:	
Flight duration	a) 10 days b) 6 – 12 months c) 5 – 10 years
Frequency of observations during the flight	Continuous (1 min averaging)
Simultaneity with other observations	Simultaneous with surface and satellite ERB meas. Simultaneous with angular and spectral flux measurements, atmospheric vertical profiles and surface properties.
Other:	
	N/A

Table 6 Platform performance requirements dictated by the Instrument Approach (ACR):

Safe payload recovery	Yes – for recalibration
Useful science payload mass	5 kg
Power draw	5 W
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	Depends on instrument field of view and desired resolution; may require knowledge. May require control to keep pointing downward
Position accuracy, including: Platform position control; Platform position knowledge.	GPS accuracy, 10 km control for regional horizontal array and 1 km for site overflight (relative to ground truth)
Calibration	Chopping, Outside constant source (sun, space)
Data storage and relay	TBD
Coordination between platforms	N/A
Other	Requires 2 separate instr. for total and SW meas. or movable filter

Table 7 Platform performance requirements dictated by the Instrument Approach (moderate resolution scanning spectrometer (S) and scanning broadband radiometer (B)):

Safe payload recovery	Yes
Useful science payload mass	100 kg (25 kg at higher cost) (S) 25 kg (B)
Power draw	100 W active (day), less then 10 W in sleep mode (night); SW channel operates during day only (S). 50-100 W (B)

Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	Knowledge of nadir angle to better than 0.1º, azimuth to about 4˚ (S, B); Control accuracy comparable to knowledge (S, B).
Position accuracy, including: Platform position control; Platform position knowledge.	GPS accuracy, 10 km control for regional horizontal array and 1 km for site overflight (relative to ground truth)
Calibration	Yes, postflight
Data storage and relay	More than 30 Mbytes/day, at least 10% telemetered (S); TBD (B)
Coordination between platforms	N/A
Other	N/A

ERB2 Vertical atmospheric profiles of P, T, h, O_3, u and v

Knowledge of the atmospheric profiles of pressure (P), temperature (T), humidity (h), ozone (O_3) and winds (u and v), obtained simultaneously with the flux measurements would allow to link these parameters to the changes in the ERB and to test the ERB models. The wind measurements are not directly related to the ERB measurements, but would be used to deduce the stability and movement of the platform. Currently existing network of meteorological radiosondes is spatially inhomogeneous and exists primarily over North American and Eurasian continents.

The measurements requirements coincide with the requirements for the flux measurements (Section ERB1). In addition, the required vertical coverage is from the platform flight altitude down to the surface, with the vertical resolution of 100 m. The horizontal resolution of the measurements would very from 15 to 1000 km - depending on the spatial extent of the observed phenomenon, number of dropsondes on each platform and on the number (density) of platforms over the observed region. The frequency of observations would very with the horizontal resolution.

Vertical profiling can be done with GPS dropwindsondes developed at NCAR/NOAA (Figure 7). Current dropwindsondes cannot measure ozone, but work is currently being done at NCAR Atmospheric Technology Division (ATD) to include the ozone measurements. Dropsondes are expendable and do not require recovery. Each one weighs about 0.4 kg. Dropsonde battery provides power for one hour of operation. Position of a deployed dropsonde is determined via GPS. No pointing knowledge or control is required. The data collected by dropsonde are relayed to the platform every 0.5 seconds. The instrument is calibrated pre-flight.

The tables below summarize the performance requirements:

Table 8 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Same as ERB1

Desired horizontal resolution within the coverage region	Depends on # of dropsondes on a platforms, platform density in the region and on observed phenomenon: From 15 to 1000 km
Desired vertical coverage	Surface to platform altitude
Desired vertical resolution	100 m
Spatial accuracy	N/A
Temporal characteristics of the measurement:	
Flight duration	Same as ERB1
Frequency of observations during the flight	Depends on platform speed and horizontal resolution
Simultaneity with other observations	Same as ERB1
Other:	
	N/A

Table 9 Platform performance requirements dictated by the Instrument Approach (dropsonde):

Safe payload recovery	No
Useful science payload mass	0.4 kg each
Power draw	Individual battery
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	N/A
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Preflight
Data storage and relay	Real time to platform, data point every 0.5 sec
Coordination between platforms	N/A
Other	N/A

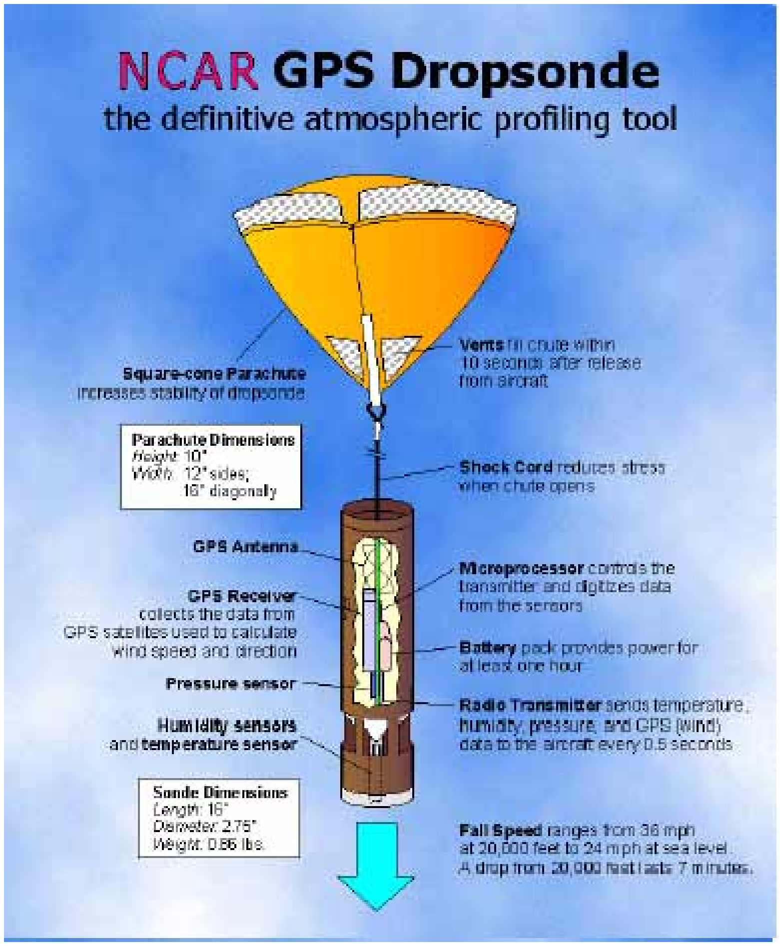


Figure 7 NCAR/NOAA GPS dropsonde

ERB3 Vertical atmospheric profiles of aerosols and cloud properties

Clouds and aerosols affect ERB by absorbing and/or reflecting the radiation. Simultaneous determination of cloud top and base heights, optical depth, cloud extinction, ice habit, asymmetry factor at more than one wavelength, liquid water content and particle mean effective radius with the flux measurements are needed to test the ERB models and to understand the changes and trends in the ERB.

The measurements requirements coincide with the requirements for the flux measurements (Section ERB1). In addition, the required vertical coverage is from the platform flight altitude down to the surface, with the vertical resolution from 50 to 100 m. The horizontal resolution is 50 to 200 m. The vertical accuracy of 1 mbar (corresponding approximately to accuracy of 10 m at 0 km and 40 m at 10 km) and horizontal position accuracy within GPS limits would be sufficient. The frequency of observations would very according to the platform speed and horizontal resolution.

These measurements could be done with cloud radar or an in situ dropsonde or profiling drone.

Cloud radar is a mm-wave polarimetric radar. Technical parameters for a space borne millimeter-wave Cloud Radar (MACSIM) are given here. Cloud radar for a stratospheric platform could probably be lighter because of the reduction in the size of the reflector. The MACSIM weighs 140 kg and consumes about 250 W of power. Peak power consumption is about 2 kW. The data rate form the instrument is 54 kbits/s.

Instruments measuring number densities of cloud particles and precipitation particles do exist as separate probed mounted on the meteorological aircraft. There are currently no dropsondes dedicated to such measurements.

In addition, these measurements would be supported with the filtered two-color imager for cloud scene/type identification. The recovery of the imager is not necessary. The imager weighs 2 kg and draws less than 10 W of power. The data volume of the imager, even compressed, is high.

The tables below summarize the performance requirements:

Table 10 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Same as ERB1
Desired horizontal resolution within the coverage region	50-200 m
Desired vertical coverage	From surface to platform altitude
Desired vertical resolution	50-100 m
Spatial accuracy	1 mbar vertical (10 m at 0 km, 40 m at 10 km) Horizontal - GPS
Temporal characteristics of the measurement:	
Flight duration	Same as ERB1
Frequency of observations during the flight	Would very with platform speed and horizontal resolution
Simultaneity with other observations	TBD
Other:	
	N/A

Table 11 Platform performance requirements dictated by the Instrument Approach (cloud radar):

Safe payload recovery	Yes
Useful science payload mass	140 kg
Power draw	250 W, 2 kW peak

Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	TBD
Position accuracy, including: Platform position control; Platform position knowledge.	TBD
Calibration	Corner reflector
Data storage and relay	54 kbits/s data rate
Coordination between platforms	N/A
Other	N/A

Table 12 Platform performance requirements dictated by the Instrument Approach (two-color imager):

Safe payload recovery	No
Useful science payload mass	2 kg
Power draw	Less than 10 W
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	Sufficient control to image the scene observed by radiometers and cloud instruments
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Preflight
Data storage and relay	High data volume
Coordination between platforms	N/A
Other	N/A

ERB4 Vertical profiles flux divergence

The measurements requirements coincide with the requirements for the cloud and aerosol properties measurements (Section ERB3).

The proposed instrument for flux divergence measurements is the radiation dropsonde. Recovery of the sonde is not required. The mass of the dropsonde is about 2 kg. The dropsonde would be gyro stabilized. Possible issues with the flux divergence dropsonde measurements include relationship between the dropsonde speed and radiometer response, and levering.

The table below summarizes the performance requirements:

Table 13 Platform performance requirements dictated by the Instrument Approach (radiation dropsonde):

Safe payload recovery	No
Useful science payload	2 kg

mass	
Power draw (include temporal profile if possible)	TBD
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	TBD
Position accuracy, including: Platform position control; Platform position knowledge.	TBD
Calibration (In flight, via ground truth, pre/post flight)	TBD
Data storage and relay	TBD
Coordination between platforms	TBD
Other	TBD

ERB5 High-resolution O_2, H_2O and CO_2 spectrometry

High–resolution observations of the oxygen A-band, water vapor band (940 nm) and CO_2 band (8-9 μm) can provide climatological statistics about cloud fields. The knowledge of the cloud fields is valuable in interpreting the scene from which the flux is measured and for climatology.

The measurements requirements coincide with the requirements for the flux properties measurements (Section ERB1). The high-resolution spectral instrument has the same characteristics as the moderate resolution spectral instrument described in Section ERB1.

3.3 Atmospheric Chemistry

The Atmospheric Chemistry group formulated the following questions to be addressed by observations from the future stratospheric platforms:

AC1. What controls water content of the stratosphere and how it is changing?

AC2. Why ozone content in lower stratosphere in midlatitudes is decreasing?

AC3. What is the budget of green house gases in the atmosphere? Why CO_2 budget is not balanced?

AC4. What are the budgets of air pollutants (like ozone)?

AC5. How can we improve hurricane paths forecast?

Even though the last question seems to be unrelated to the Atmospheric Chemistry theme, the group participants felt that it should be addressed, because the use of stratospheric platforms can offer an unprecedented opportunity to observe the hurricanes.

The advantages of using the stratospheric platforms are:

- High-resolution in-situ measurements
- In-situ validation of satellite measurements
- Higher resolution and S/N of remote sensing instruments
- 100 day flight would provide snapshot of evolving stratospheric trace gas structure

The following sections describe the measurements, instrument approaches and mission scenarios corresponding to the list of questions posed above.

AC1 Monitoring water vapor budget in stratosphere

Key climatological questions are related to the region of the tropical atmosphere between 14 and 20 km, around the tropopause. Figure 8 schematically illustrates the structure of the atmosphere in this region. This region is important climatologically because it is the source region for the bulk of the air that is transported from the troposphere into the lower stratosphere. It is also the region where the mixing ratio of water vapor entering the stratosphere is determined. Water vapor is the most important greenhouse gas in the atmosphere and its stratospheric mxing ratio can have a significant effect on the Earth’s climate. The increase of water in the stratosphere can also lead to larger ozone holes that persist for longer times. Thus, it is important to know what processes control the transport of water in the tropopause region.

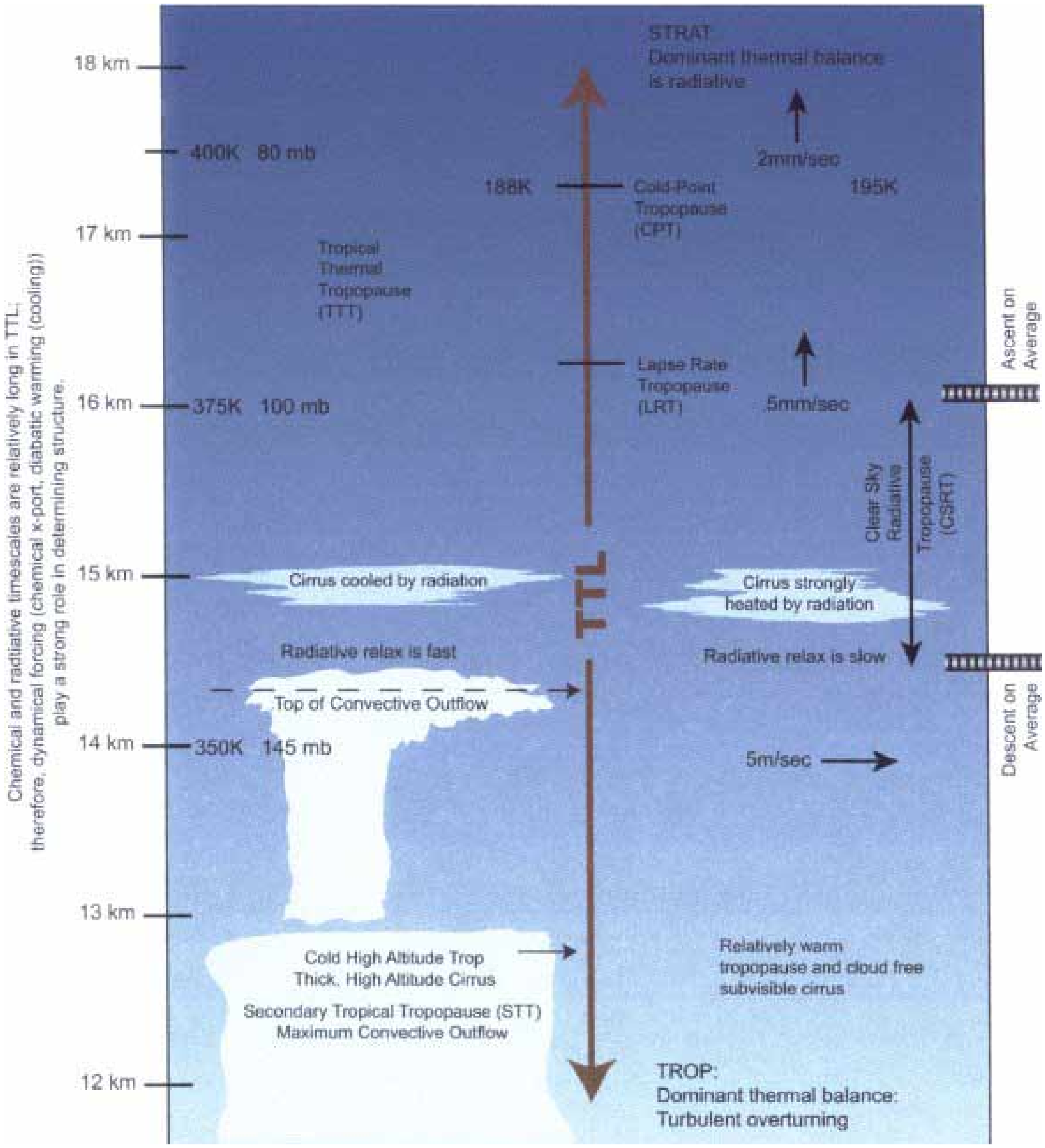


Figure 8 Atmospheric Structure from 14 to 20 km

In situ measurements are needed in this region to resolve the small vertical structure of the changes that are occurring that cannot be resolved with the satellite observations. Above 20 km the gradients of water vapor with altitude, latitude, and longitude are small enough so that the satellite-borne instruments are able to provide the required observations. However, the satellite instruments detect seasonal signature in water vapor than extends to higher altitudes than the in situ measurements. Thus, one may argue that in situ measurements are needed not only in the 14 to 20 km region, but also all the way up to 30 to 35 km.

Whether water vapor of the stratosphere is increasing or not is a controversial question. There are unresolved issues with the accuracy of the existing measurements and their long-term trends.

Instrument intercomparisons detailed in Chapter 2 of the December 2000 SPARC (Stratospheric Processes And their Role in Climate) Assessment of Upper Tropopsheric and Stratospheric Water Vapor show 20-30% differences between instruments that remain unresolved. Figure 2.69 in chapter 2 illustrates that trend determinations can depend both on the instrument used as well as the time period chosen. Also, water vapor measurements made with the instrument that most convincingly shows an increasing trend in water vapor (the Frost Point Hygrometer) exhibits differences of up to 30% when compared with other in situ instruments.

To monitor stratospheric water vapor one has to simultaneously measure methane and molecular hydrogen too, because they affect the water content through oxidation. Molecular hydrogen, however, is typically present at concentrations of 0.5 parts per million with little variability. Thus, the stratospheric payload focused on water vapor monitoring the stratospheric water vapor budget would simultaneously measure water, methane, pressure and temperature.

If the changes in water vapor content are indeed occurring, the related question is what causes them? If the changes in water vapor concentration are inconsistent with methane changes alone, one would have to look for an alternative explanation. The simplest hypothesis is that the temperature of the tropical tropopause controls the stratospheric water content. The dehydration occurs when air rising in the upper tropical troposphere passes through a temperature minimum, typically called the cold-point tropopause. Ice particles would form, grow and condense out leaving a water vapor mixing ratio determined by the vapor pressure of water at that temperature. The changes in stratospheric water would thus track changes in the temperature of the tropical tropopause.

While there is some published evidence that stratospheric water vapor is consistent with cold-point tropical tropopause temperatures, these temperatures have been decreasing while stratospheric water vapor is reportedly increasing. It is not clear that a single measurement cannot answer the question of what controls the water content of the stratosphere. A set of complex measurements will need to be performed in the upper troposphere (below the tropopause) and lower stratosphere to determine the processes that dehydrate the air entering the stratosphere. In addition to the monitoring measurements, one would measure CO_2, CO, isotopic water (HOD and H_2O^{18}) to trace thermodynamic history of the air parcel, and vertical velocities. The measurements would need to be made continuously over an extended region, because of the different mechanisms that could be responsible for the dehydration. Todays aircraft cannot provide continuous measurements, thus one would look for constellations of long duration stratospheric platforms to perform this measurements.

The constellation would cover the tropical and region and midlatitudes. The poles do not need to be covered. The platforms would be concentrated in the tropical region (between 15º N and 15º S) – 20 to 30 platforms, with about 5 platforms in midlatitudes. The number of platforms should be sufficient to study different atmospheric flow regimes (jets, monsoons, etc.). The measurements would cover the regions from 14 to 20 km (to see the seasonal cycle) and from 20 to 35 km (for the annual cycle of water) with the vertical resolution of 100 m or better (ideally - continuously). The required flight duration sufficient to obtain a “snapshot” of a season or to observe a transitional season (spring/summer) is about 90 days. During this time the simultaneous observations of the relevant species and parameters must be made once a day.

These measurements could be made in conjunction with the ozone measurements (see Section AC2).

Water and methane would be measured in situ via multipass IR absorption. Two instruments would be needed – one for water, the other one – for methane. Typical instrument weighs 25-50 kg today, but the mass could be reduced to 5 kg in 10 years. The instrument power draw is 20 W. The instrument inlet must be oriented along the airflow. The instrument is self-calibrating and has a low data rate. Some coordination between the platforms in the constellation would be necessary, - to keep the platforms apart, or to position the platforms to measure the same air parcel for validation purposes.

CO_2 can be measured with a similar instrument, except for calibration gases, which would make the instrument a bit heavier and may require more power.

The tables below summarize the performance requirements:

Table 14 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Tropics (15º S – 15º N) and midlatitudes
Desired horizontal resolution within the coverage region	20-30 platforms in tropics; 5 platforms in midlatitudes.
Desired vertical coverage	14-20 km (seasonal cycle) 20-35 km (annual cycle)
Desired vertical resolution	100 m
Spatial accuracy	±5º (to resolve region boundaries)
Temporal characteristics of the measurement:	
Flight duration	Largest possible, at least 90 days
Frequency of observations during the flight	1/day
Simultaneity with other observations	Simultaneous with CO_2 and meteorology
Other:	
	Can be done in conjunction with ozone meas.

Table 15 Platform performance requirements dictated by the Instrument Approach (in situ multipass IR absorption):

Safe payload recovery	Yes
Useful science payload mass	25-50 kg (today), 5 kg (tomorrow)
Power draw	20 W
Pointing accuracy,	Inlet oriented along the flow

including: Platform attitude control; Platform attitude knowledge.	
Position accuracy, including: Platform position control; Platform position knowledge.	Within GPS limits
Calibration	Self calibrating
Data storage and relay	Low data rate
Coordination between platforms	Rough coordination to keep platforms apart or for pulling them together for validation meas.
Other	CO2 is similar instr., except for calibration gases, which would make heavier instr.

AC2 Monitoring trends in stratospheric ozone

Ozone in lower northern lower midlatitude stratosphere has been decreasing by about 1%/year for the last 10 years. The question is whether this is due to in situ destruction by chlorine chemistry or is it a dynamics effect. To test the dynamics hypothesis one would need a constellation of stratospheric platforms covering an extended area of the atmosphere, because ozone is brought into lower midlatitude stratosphere from different regions, the upper stratosphere, the lower tropical stratosphere, and the upper tropical troposphere. To monitor ozone and to relate ozone change to a change in atmospheric transport requires a simultaneous measurement of CO_2, which gives not only the average stratospheric age of the air but also information on the component of the air mass that recently came from the tropics. By adding the ozone instrument to the payload described in Section AC1 one can "kill two birds with one stone" – to monitor both the water and the ozone. The ozone-monitoring constellation would have 20 to 25 platforms in northern midlatitudes (between 35º an 50º N). The number of platforms should be sufficient to capture the structure of the circulation affecting the ozone. The observations would need to be more frequent than once per day, the exact number being constrained by consumables, energy, etc.

The ozone would be measured by in situ absorption instrument. The mass of a typical instrument today is 20 kg, but it can be expected to drop to 3 kg in 10 years. The instrument power draw is 10 W. The instrument uses small pumps or direct flow.

The tables below summarize the performance requirements:

Table 16 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Northern midlatitudes (35º-50º N)
Desired horizontal resolution within the coverage region	20-25 platforms in a midlatitudes band
Desired vertical coverage	14-20 km (below ozone layer)

Desired vertical resolution	100 m
Spatial accuracy	Uniform coverage
Temporal characteristics of the measurement:	
Flight duration	Largest possible, at least 90 days
Frequency of observations during the flight	More than 1, depending on power, consumables constraints
Simultaneity with other observations	CO_2, P, T
Other:	
	N/A

Table 17 Platform performance requirements dictated by the Instrument Approach (in situ absorption):

Safe payload recovery	Yes ($50K each instrument)
Useful science payload mass	20 kg (today) 3 kg in 10 years
Power draw	10 W
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	N/A
Position accuracy, including: Platform position control; Platform position knowledge.	Within GPS limits
Calibration	none
Data storage and relay	Low data rate
Coordination between platforms	Rough coordination to keep platforms apart or for pulling them together for validation meas.
Other	Small pump for slow flow; Same CO_2 meas. as for AC1

AC3 High-resolution, high-accuracy monitoring of surface sources/sinks of CO_2 and other greenhouse gases

One of the strongest drivers of the warming trends in the Earth atmosphere seems to be CO_2 that has been steadily increasing in the atmosphere since the industrial revolution. Because of this it is important to know the budget of the CO_2 in the atmosphere. To calculate the budget of the CO_2 one has to account for various sources of the CO_2, such as biomass burning, and sinks, such as plants, oceans, etc. Based on currently available data, the budget does not come out right – it is inconsistent with the observed increase of the CO_2 in the atmosphere. The same is true for the budgets of the other greenhouse gases. Thus, global monitoring of the CO_2 (and other greenhouse gases) fluxes is needed to establish the budget. The monitoring assumes remote high-resolution observation of the sources on the ground to identify the so-called "hot spots" of CO_2 emission or absorption. The problem with the satellite measurements is that observations from space measure the total atmospheric CO_2 column, while the perturbations at the surface are very small. The global total concentration of the CO_2 in the atmosphere varies by about 5% seasonally and between the northern and the southern hemispheres. Observations need to be made at greater detail, greater precision and with higher spatial resolution at places that are really active to pick up much smaller sources and sinks in the background.

Long-term stratospheric platforms offer an unprecedented opportunity to monitor concentrations of atmospheric species and CO_2 in particular with LIDARs. LIDARs are hard to use for this purpose from space, because even at Low Earth Orbits (LEO) the LIDARs require large telescopes and powerful lasers. At 35 km the signal is 100 times stronger than at 350 km (typical LEO orbit) or 400 times stronger than at 700 km (sun synchronous orbit) and LIDARs may not need telescopes or a powerful laser.

Another advantage of the use of the stratospheric platforms is the increased time of observation of localized regions that would allow to see the daily dynamics of the source/sink. Polar LEO satellites are only able to observe a given point on the surface twice a day.

Constellations of several hundred stratospheric platforms can provide coverage comparable to coverage from a polar satellite. The cost of multiple expensive instruments (LIDARs) may make this option impractical. On the other hand, global coverage is not required. There is already some understanding of where the important spots are. For example, no coverage is required over Arctica (although it may be possible), because the CO_2 fluxes are usually linked to biological activity.

The suggested application is also applicable for monitoring greenhouse emission treaty obligations.

Initially, the payload will contain instruments to measure CO_2. Observations of other greenhouses gases are dependant on the development of smaller sensors.

The observations are required between 70° N to 70° S. It is not clear at the moment what horizontal resolution of the constellation would be required, because it depends on the dimensions of the source, but it probably would need to be more or less uniform. The instruments would measure concentrations below the boundary layer or the total column abundance. The measurements would need to be made for the maximum achievable duration of the flight and continuously during the flight. Topography may need to be measured simultaneously with the other measurements, to provide context for the total column abundance. The number of species that can be measured from a single platform would be determined by power constraints. A separate LIDAR or passive instrument would be need for every species.

LIDAR is an expensive instrument and safe recovery after flight termination is required. Currently typical LIDAR weighs 100 kg and requires 1 kW of continuous power. There are no specific requirements on pointing accuracy. The data rate is low (10 to 100 Kbytes/day)

A passive instrument, such as interferometer, spectrometer, reflected sunlight radiometers or similar, can be used to measure concentrations of greenhouse gases and specifically CO_2. These instruments are also expensive (although less expensive than LIDARs), and safe recovery after flight termination is required. A typical instrument would have a mass of about 20 kg and require 20 W of power. The length of the measured atmospheric column would need to be known to better than 10 m for observations from 35 km, or topography needs to be known. The platform and instrument altitude and attitude would need to be known to provide the desired accuracy in column length determination. The instruments can be calibrated in flight by pointing at known surface target or by looking at calibration source on board through a flipping mirror. The data rate of the passive instruments is similar to that of the LIDAR.

The following tables summarize the performance requirements:

Table 18 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Global (70º S – 70º N)
Desired horizontal resolution within the coverage region	Depends on the scale of the source, but more or less uniform
Desired vertical coverage	Below the boundary layer or total atm. column meas.
Desired vertical resolution	N/A
Spatial accuracy	N/A
Temporal characteristics of the measurement:	
Flight duration	As long as possible
Frequency of observations during the flight	Continuous
Simultaneity with other observations	Topography; Other greenhouse gases
Other:	
	Multiple species on the same platform, given the power constraints. Separate LIDAR or passive instr. For every specie.

Table 19 Platform performance requirements dictated by the Instrument Approach (LIDAR):

Safe payload recovery	Yes (essential)
Useful science payload mass	100 kg (25 kg in 10 years)
Power draw	1 kW continuous
Pointing accuracy, including: Platform attitude control; Platform	No

attitude knowledge.	
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Self calibrating
Data storage and relay	10-100 Kbytes/day (low data rate)
Coordination between platforms	Multiple platforms spaced out
Other	100 fold increase in signal compared to observations from LEO (350 km); 400 fold increase over sun synchronous orbit (700 km)

Table 20 Platform performance requirements dictated by the Instrument Approach (passive instrument: interferometer, spectrometer, or similar):

Safe payload recovery	Yes (expensive)
Useful science payload mass	20 kg
Power draw	20 W continuous
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	Knowledge with the accuracy equivalent to the column depth knowledge accuracy of 10 m from 35 km; or knowledge of topography
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Surface target; Flip mirror for onboard calibration; Constant sources
Data storage and relay	10-100 Kbytes/day (low data rate)
Coordination between platforms	Multiple platforms spaced out
Other	N/A

AC4 Monitoring pollution events and tropospheric ozone over urban areas

Another class of important questions that is just starting to emerge is related to air pollution. Air pollution can be both a global and regional problem: for example, dust from Asian continent is observed to reach the North American continent. At the same time air pollution is observed over urban areas.

The surface monitoring stations are unable to provide the desired coverage, while satellites at LEO are unable to observe a particular spot (for example, a city) more than twice a day. What is needed is continuous coverage over places that are known sources of pollutants.

Different spots would emit different pollutants, - for example, pollution around a plastics factory would differ from pollution around a freeway. However, ozone is commonly present in the smog over urban areas. It is hard to monitor tropospheric ozone concentrations from space, because of the stronger signal from the stratospheric ozone layer. Most of the stratospheric ozone is between 19 and 33 km. If the ozone observing instrument can be deployed from a stratospheric platform (from a tether or by other means) below or near the bottom of the stratospheric ozone layer (to 17 km), then the ozone layer signal will not block the signal from the tropospheric ozone.

Even for observations from within the ozone layer the use of LIDAR may offer significant benefits due to the increase of the tropospheric signal. Another way to observe tropospheric ozone is to measure the total column abundance, because typically changes in the column over short distances can be inferred to result from changes in the tropospheric component of the column.

Ozone monitoring must necessarily include monitoring of all the species relevant for ozone chemistry, such NO_x, SO_2, CO, other organic compounds. It may, however, be unrealistic to put all the necessary remote sensing instruments one a single dedicated platform.

Most of these species have infrared (IR) features and can be observed spectroscopically from higher altitudes with interferometers, radiometers (in some cases), LIDARs, and microwave instruments. Currently, such instruments are operating in space to make measurements the stratosphere. However, it may only be possible to observe ozone from the stratosphere.

For the monitoring application, an observing platform would need to be positioned over the major city or source (to cover area 20 by 20 km). Big pollution events, such as a dust cloud from the Asian continent, may require several platforms positioned off the coast of China, for example. The desired horizontal resolution within the source would be 1 km – to resolve the small structure. Again, the vertical coverage would be limited to the boundary layer. The vertical resolution of the measurements would need to be of the order of 300 m. The measurements would need to be made for the maximum achievable duration of the flight and continuously during the flight. Measurements of all pollutants are required at the same time (to study the budgets). The instruments fro this payload are the same as in Section AC3. It may be possible to measure some species at night, depending on particular instrument and resolution.

The tables below summarize the performance requirements:

Table 21 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	Station keeping over major city or source; 20 by 20 km area
Desired horizontal resolution within the coverage region	1 km within the source to resolve small structure
Desired vertical coverage	Within the boundary layer
Desired vertical resolution	300 m
Spatial accuracy	Sufficient to see the source
Temporal characteristics of the measurement:	

Flight duration	As long as possible
Frequency of observations during the flight	Continuous
Simultaneity with other observations	All pollutants at the same time (NO_x, SO_2, CO, O_3, etc)
Other:	
	N/A

Table 22 Platform performance requirements dictated by the Instrument Approach (LIDAR):

Safe payload recovery	Yes (essential)
Useful science payload mass	100 kg
Power draw	1 kW continuous
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	No
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Self calibrating
Data storage and relay	10-100 Kbytes/day (low data rate)
Coordination between platforms	Multiple platforms spaced out
Other	100 fold increase in signal compared to observations from LEO (350 km); 400 fold increase over sun synchronous orbit (700 km)

Table 23 Platform performance requirements dictated by the Instrument Approach (passive instrument: interferometer, spectrometer, or similar):

Safe payload recovery	Yes (expensive)
Useful science payload mass	20 kg
Power draw	20 W continuous
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	Knowledge with the accuracy equivalent to the column depth knowledge accuracy of 10 m from 35 km; or knowledge of topography
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Surface target; Flip mirror for onboard calibration; Constant sources

Data storage and relay	10-100 Kbytes/day (low data rate)
Coordination between platforms	Multiple platforms spaced out
Other	Some species might be measured at night, depending on particular instrument, resolution

AC5 Hurricane's "steering wind" measurements

Another potential application for stratospheric platforms involves remote wind measurements with LIDARs. Currently, a lot of effort is concentrated on measuring winds from space with LIDARs. A constellation of stratospheric platforms capable of providing comparable coverage would probably cost too much due to the high cost of the LIDARs. However, stratospheric platforms can be employed in a more "localized" application, such observation of winds around a hurricane. Hurricane path depends on the so-called "steering winds" – the winds that "surround" a hurricane. 20 LIDARs could be enough to get valuable information about a hurricane path. By measuring the "steering winds" it may be possible to reduce the uncertainty in determination the location of the hurricane landfall. It is estimated that reducing the uncertainty by 1 mile can save about $1M in evacuation and related costs per episode. Reducing the uncertainty by 100 miles will save $100M for just one episode, which is much more than the cost of the constellation and the instruments.

The tables below summarize the performance requirements:

Table 24 Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	"Steering winds" around a hurricane
Desired horizontal resolution within the coverage region	TBD
Desired vertical coverage	From surface to top of a hurricane
Desired vertical resolution	TBD
Spatial accuracy	TBD
Temporal characteristics of the measurement:	
Flight duration	Sufficient to observe a hurricane before the landfall – 3-5 days
Frequency of observations during the flight	TBD
Simultaneity with other observations	TBD
Other:	
	TBD

Table 25 Platform performance requirements dictated by the Instrument Approach (LIDAR):

Safe payload recovery	Yes (essential)
Useful science payload mass	100 kg
Power draw	1 kW continuous
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	TBD
Position accuracy, including: Platform position control; Platform position knowledge.	GPS
Calibration	Self calibrating
Data storage and relay	TBD
Coordination between platforms	TBD
Other	100 fold increase in signal compared to observations from LEO (350 km); 400 fold increase over sun synchronous orbit (700 km)

4 Summary

This document summarizes the results of the RASC Science Workshop held in Greenbelt, MD on June 19, 2002. During the workshop three groups of scientists identified potential science applications for future stratospheric platforms for Atmospheric Chemistry, Geomagnetism and Earth Radiation Balance. From these applications we identify driving performance requirements for stratospheric platform development. The performance requirements are summarized in Tables Table 1-Table 25.

The workshop showed that stratospheric platforms have a potential to make a significant impact in these three scientific areas.

The Geomagnetism group identified several areas for potential applications of stratospheric platforms. They can be used to study the nature of the middle and lower crust, to monitor the South Atlantic magnetic anomaly, to study the sub-ice circulation in Polar Regions, to detect natural hazards through their associated magnetic signatures and to study stratospheric/atmospheric processes with magnetic signatures. Stratospheric platforms allow a number of advantages over current platforms (satellites, aircrafts, surface stations) used in geomagnetic surveys, such as the ability to reliably separate the internal and external components of the Earth’s magnetic field by measuring vertical filed gradients, access hard to reach sites, add intermediate spatial wavelength components to the existing surveys and to warn spacecraft about space weather events.

The Earth Radiation Balance (ERB) group identified the verification of satellite measurements by direct measurements of ERB fluxes from the top-of-atmosphere (TOA) as the main application for stratospheric platforms. The ERB group defined measurements and proposed relevant instrumentation approaches that would allow characterizing the ERB variations on the global, climate scale and on the smaller, synoptic scale. These measurements include broadband and spectral angular measurements of ERB fluxes, simultaneous determination of atmospheric parameters (pressure, temperature, humidity), and cloud and atmospheric aerosols parameters. One of the major advantages of stratospheric platforms for ERB measurements is the direct measurement of the ERB fluxes that does not require radiance-to-flux conversion (satellites only measure radiance). Other advantages of ERB observations from stratospheric platforms versus satellites are the ability to observe flux dynamics on temporal scales that are not available from satellites, capability of relatively large payloads (compared to satellites) and the related ability to make simultaneous in situ and remote measurements with different instruments.

The Atmospheric Chemistry group identified several applications for potential applications of stratospheric platforms. Stratospheric platforms can be used to monitor water content of the stratosphere and study the processes that may be changing it, to monitor and study the decrease of ozone content in lower stratosphere in northern midlatitudes, to study the budget of green house gases (primarily CO_2) in the atmosphere, monitor air pollutants (like ozone) over urban areas. The advantage of being closer to Earth (than satellites) may allow reducing the size and cost of LIDARs and placing them on stratospheric platforms for atmospheric wind measurements. Such measurements may improve the ability to forecast hurricane paths. Other advantages offered by stratospheric platforms include high-resolution in-situ measurements, in-situ validation of satellite measurements, higher resolution and higher signal-to-noise ratio of remote sensing instruments, and ability to provide a snapshot of evolving stratospheric trace gas structure.

The performance requirements associated with these applications and measurements will be used to evaluate capabilities of existing and proposed stratospheric platforms.

Appendix A: Meeting Plan and RASC Study Overview

Revolutionary Stratospheric Platforms for Earth Science Phase I

Meeting Plan and RASC Study Overview

Presentation to RASC Workshop

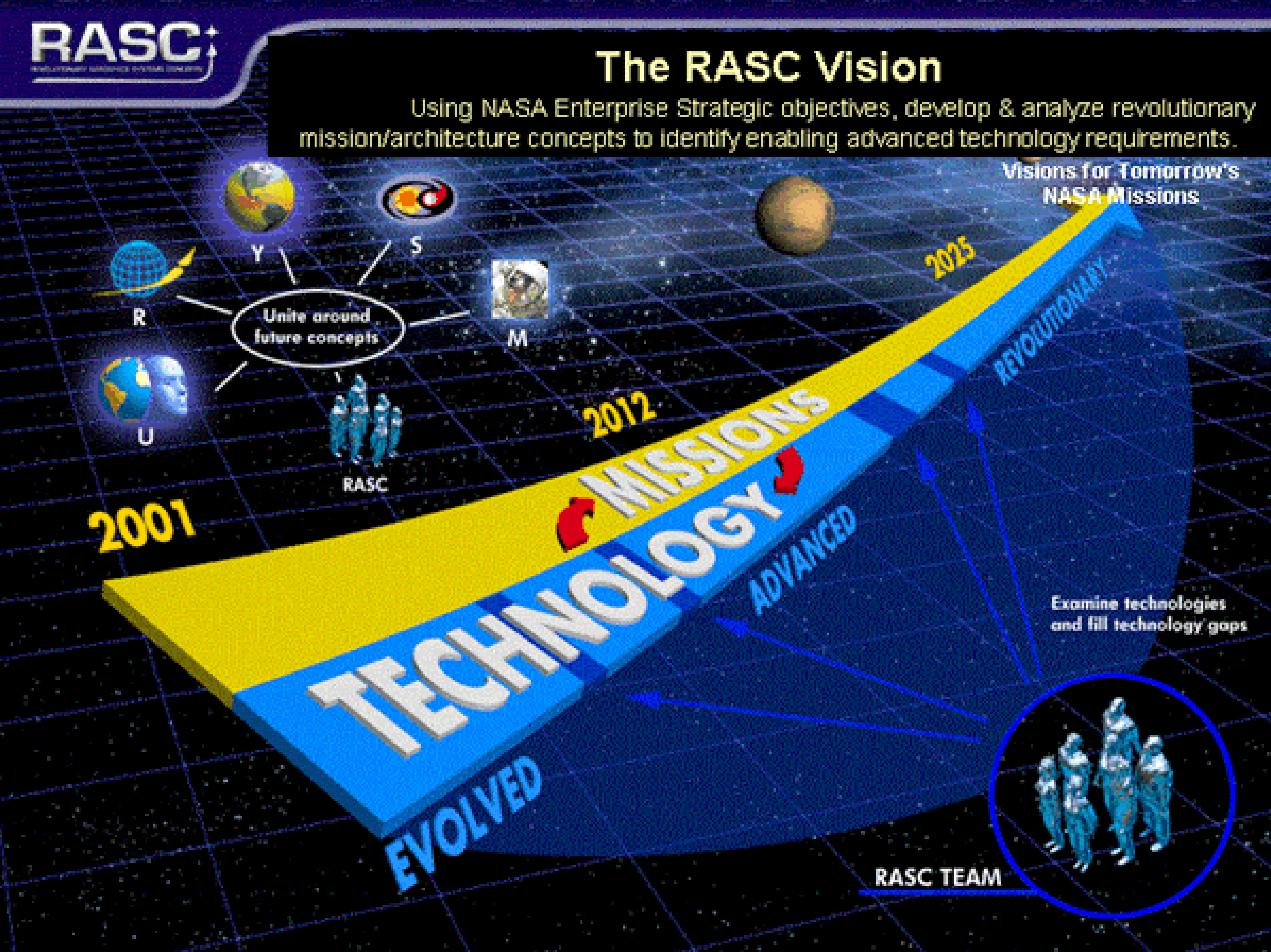
By Dr. Matthew Kuperus Heun
Global Aerospace Corporation
http://www.gaerospace.com/

19 June 2002

Global Aerospace Corporation

Meeting Agenda

- 8:00–8:30 Registration
- 8:30–8:45 Plan for the RASC study and workshop (Heun)
- 8:45–9:00 Introduction (Wiscombe)
- 9:00–9:40 Overview of stratospheric platforms (Nock)
- 9:40–10:00 Break
- 10:00–10:30 Instructions for breakout sessions (Pankine)
- 10:30–12:00 Begin breakout sessions (all)
- 12:00–13:00 Lunch
- 13:00–14:30 Finish breakout sessions (all)
- 14:30–15:30 Prepare breakout session reports (all)
- 15:30–15:45 Break
- 15:45–17:00 Breakout session reports (Heun, moderator)


RASC
The RASC Vision
Using NASA Enterprise Strategic objectives, develop & analyze revolutionary mission/architecture concepts to identify enabling advanced technology requirements.
Visions for Tomorrow's NASA Missions
R
Y
S
M
U
Unite around future concepts
RASC
2001
2012
2025
MISSIONS
TECHNOLOGY
EVOLVED
ADVANCED
REVOLUTIONARY
Examine technologies and fill technology gaps
RASC TEAM

RASC Objectives

- Enable future NASA missions by
  - Developing aerospace systems concepts
  - Technology requirements
- The RASC Program applies a “top-down” perspective to explore new mission capabilities and discover “What's possible”
- Maximize the benefits of revolutionary capabilities that span across NASA Enterprises
- Initial focus: identifying and evaluating revolutionary systems concepts

RASC "Top-Down" Methodology

- Using a 25-year vision perspective, identify the desired new capabilities derived from NASA Enterprise objectives and priorities
- Define integrated systems approaches (architectures) and their required functional capabilities or engineering challenges
- Develop revolutionary systems concepts to provide these capabilities
- Conduct systems trade studies to define the enabling technology requirements and levels of performance needed to meet the challenges
- Recommend the most promising revolutionary concepts with their integrated system payoffs and key enabling technology requirements

Background & Motivation for this RASC Study

- Significant potential Earth science benefits from stratospheric platforms with
  - Long duration (> 100 days)
  - Autonomous coordination (data relay, position correction, and notification in the event of problems)
  - *In-situ* measurement capabilities

- Architecture for such measurements provides unique and challenging opportunities

Potential Earth Science Applications

- Atmospheric Chemistry
  - Few actual profiles of chlorine and bromine (< 1 balloon launch per year)
  - 100-day flight would provide snapshot of evolving stratospheric trace gas structure
- Earth Radiation Balance
  - Fluxes at the top-of-the-atmosphere are primary drivers for climate change
  - Satellites measure radiance, not flux
  - Dynamics of the flux (hourly and daily synoptic variation) are unknown
  - 100 platforms around the globe would measure flux directly and provide dynamics
- Geomagnetism
  - Non-uniform distribution of existing, land-based observatories
  - Stratospheric platforms could act as proxies for geomagnetism observatory and provide data over oceans
  - Accurate data for mineral and petroleum exploration

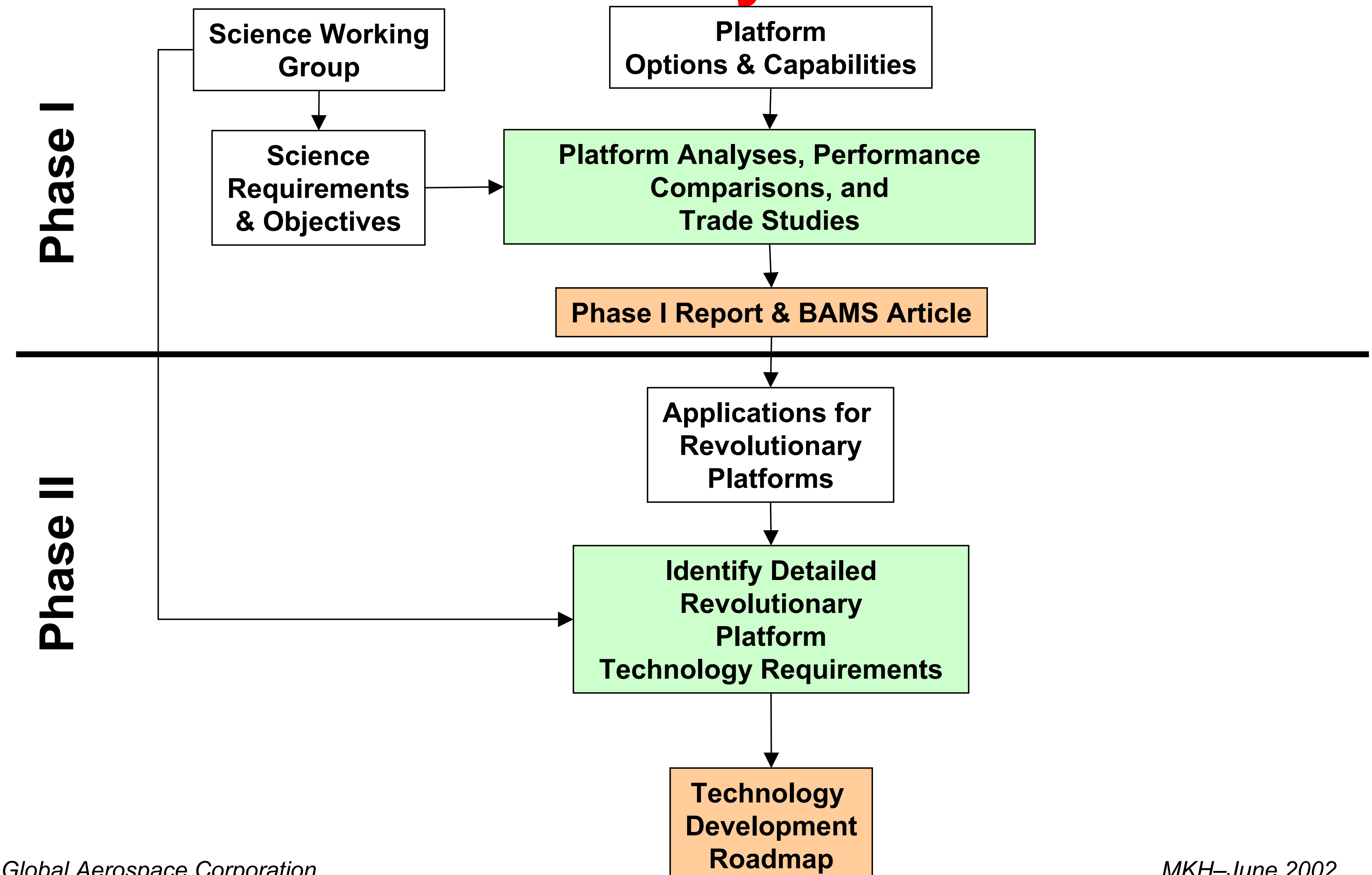
Potential Benefits

- Low-cost, high-altitude (35 km) platform above 99% of Earth's atmosphere
- *In-situ* measurements eliminate assumptions inherent in remote sensing of same quantity
- Long-life platform provides high accuracy (through averaging) if errors are random
- Continuity of long-term climatological observations
- Instrument recovery allows post-flight verification
- Easy upgrade to new technologies: recover and re-launch
- Validation of space-borne instruments

Key Development Challenges

- **Long-duration (>100 days) flights**
- **Steerable platform (into and out of polar vortices)**
- **Launch location and time flexibility**
- **Reliable operation and payload recovery**
- **Precise orientation and pointing knowledge**
- **Power**

Study Process



Phased Approach

- **Phase I: Evaluate Architecture Options for Earth Science**
  - Systems perspective
  - Examine various platform alternatives
  - Identify strengths of platform systems for meeting science objectives
  - Identify mission applications that deserve further study
  - Completion date: ______________________

- **Phase II: Technology Roadmap**
  - 25 year time frame
  - Infrastructure needs
  - Technology needs
  - Proposal submitted, decision imminent

Study Objectives & Products

- **Objectives**
  - Phase I: Identify suitable platforms for future revolutionary stratospheric *in-situ* measurements
  - Phase II: Roadmap the technologies necessary for the development of such platforms

- **Phase I products**
  - Science workshop report
  - Written final report
  - BAMS article

Overview of Tasks

- **Identify science goals for stratospheric platforms**
- **Platform identification and comparison**
- **Platform evaluation**
- **Reporting**

Identify Science Goals

- **Create a 3-person Earth Science Working Group (ESWG)**
  - One expert from each science discipline area being covered
  - Experts develop science concepts, mission options, and science requirements
- **Convene a science workshop**
  - ESWG members lead participants for each science area
    - Identify ESE strategic plan objectives to be addressed by stratospheric platforms
    - Identify measurement requirements, instrument approaches, and science requirements driving platform design
  - Develop requirements in several Earth science areas

Platform Identification and Comparison

- Understand science goals as developed by the Earth Science Working Group and the Earth science workshop
- Access literature and research stratospheric platform systems and concepts
- Develop list of potential stratospheric platforms with required capabilities
- Compare candidate platforms to stated requirements
- Consider both present and future capabilities in RASC context

Evaluate Platforms

- Develop objective stratospheric platform evaluation criteria
- Perform trade studies and independent analysis
- Use scaling models for candidate platforms
- Evaluate the suitability of each potential platform for meeting science goals and requirements developed at the workshop
  - Payload capability, platform size, and cost
  - Launch and payload recovery operations
  - Trajectory control capabilities
  - Airborne life-limiting factors
  - etc.
- Prioritize potential platforms by their suitability for meeting science goals

Reporting

- Science workshop report
- Written final report
- BAMS article
- Monthly reports
- Weekly tag-ups

Stated Stratospheric Platform Capabilities

- **30- to 35-km (98 to 115 kft) constant altitude**
- **100-day flights (eventually 365 days)**
- **1 kW of power - continuous?**
- **200 kg (440 lbs.) or more payload capacity**
- **Payload recovery at end of flight**

In addition:

Make in situ measurements between 20-35 km altitude

The Task at Hand

- Develop Earth science mission scenarios
  - Responsive to ESE questions (or future questions)
  - Utilize stated platform characteristics
- Develop measurement strategies
- Develop instrument approaches
- Develop measurement requirements
- Identify potential additional platform requirements
  - Simultaneity with other measurements
  - Multi-platform coordination
  - Trajectories and flight paths
  - etc.

Work Process for Today

- Work in groups
- Use data-capture questionnaire
- Tape recorders
- Scribe for each group
- Develop a written group report
- Report back to group at 15:45

Summary

- NASA's ESE could benefit tremendously from long-duration autonomously coordinated *in-situ* measurements in the stratosphere
- Platform architecture is unique and challenging
- Development of the platform architecture would revolutionize Earth science by answering fundamental questions about
  - Atmospheric chemistry
  - Earth radiation balance
  - Geomagnetism

Meeting Agenda

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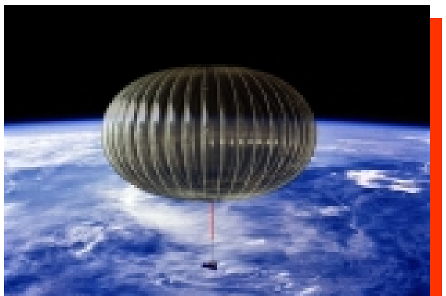
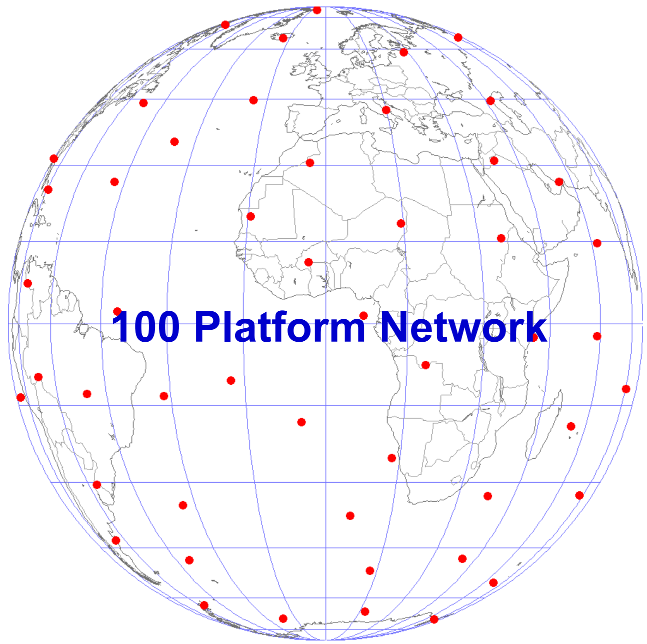
- 15:30–15:45 Break
- 15:45–17:00 Breakout session reports (Heun, moderator)

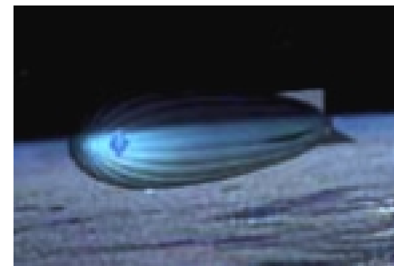
Appendix B: Stratospheric Platform Options

RASC STRATOSPHERIC PLATFORM EARTH SCIENCE WORKSHOP

STRATOSPHERIC PLATFORM OPTIONS







Kerry T. Nock
Global Aerospace Corporation
http://www.gaerospace.com/

19 June 2002

Global Aerospace Corporation

Topics

Purpose

Plan

Stated Revolutionary Platform Capabilities

Platform Options

Current / Revolutionary Platform Comparison

Evaluation Criteria

Development Challenges

Summary

Purpose of Briefing

- Discuss future study plans
- Provide you background on existing and revolutionary platform capabilities
- To refresh memories and stretch your minds about platforms beyond what is available today

Plan for Developing Stratospheric Platform Options

- Identify and compare platform options
- Evaluate platform options relative to stated capabilities and Earth science objectives

Platform Identification and Comparison

- Understand science goals as developed by the Earth Science Working Group and the Earth science workshop
- Access literature and research stratospheric platform systems and concepts
- Develop list of potential stratospheric platforms with required capabilities
- Compare candidate platforms to stated requirements
- Consider both present and future capabilities in RASC context

Evaluate Platforms

- **Develop objective stratospheric platform evaluation criteria**
- **Perform trade studies and independent analysis**
- **Use scaling models for candidate future platforms**
- **Evaluate the suitability of each potential platform for meeting science goals and requirements developed at the workshop**
- **Prioritize potential platforms by their suitability for meeting science goals**

Revolutionary Stratospheric Platform Capabilities

- 30- to 35-km constant altitude
- 100-day flights (eventually 365 days)
- 1 kW of power
- 200 kg or more payload capacity
- Make in situ measurements between 20-35 km altitude
- Payload recovery at end of flight

Stratospheric Platform Options

Preliminary Filter for Selection of Stratospheric Platform Options

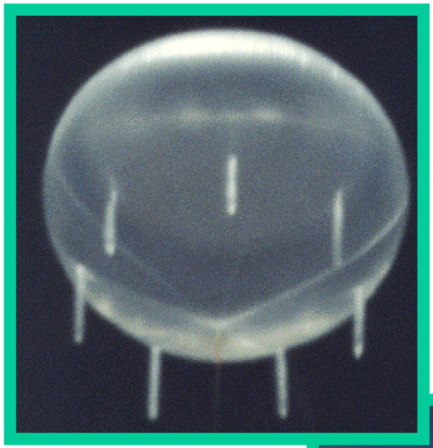
- Sustained flight above 60,000 ft altitude
- Historical, operational, currently under development and/or test and conceptual

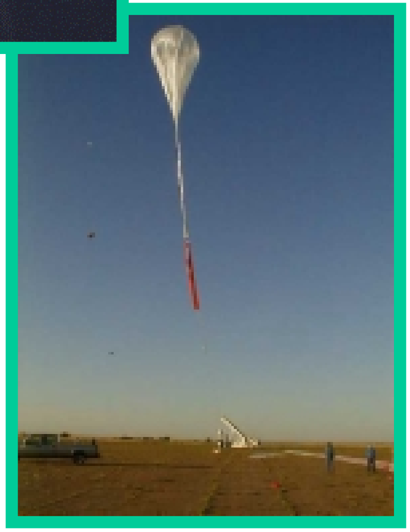
Piloted Aircraft

- Historical
  - SR-71 (stored)
- Operational
  - ER-2
  - U-2
  - WB-57F
  - Mig-25
- Under development
  - Proteus

Balloons

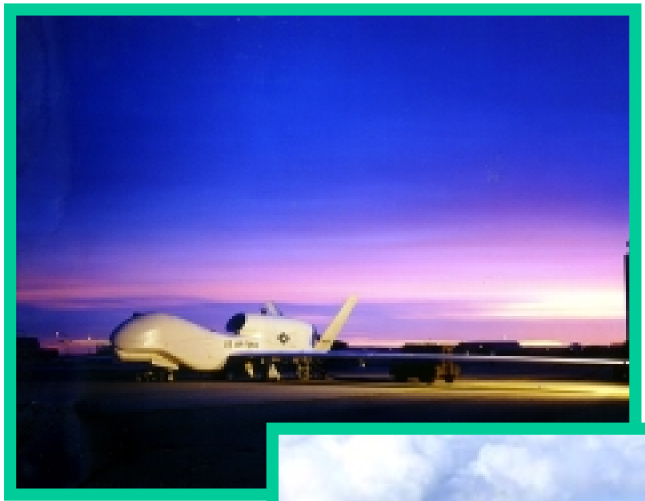
- **Historical**
  - Small super-pressure
  - Racoon
  - Anchor
- **Operational**
  - Conventional zero pressure (ZP)
  - Polar summer zero pressure (LDB)
  - IR hot air (MIR)
- **Under development**
  - Ultra-long Duration Balloon (ULDB) - NASA
  - GAINS Anchor - GSSL
- **Concepts**
  - Advanced Zero Pressure
  - Guided stratospheric super-pressure





Unnamed Air Vehicles (UAVs)

- Historical
  - Perseus B
  - Raptor
  - Altus II
  - Pathfinder
- Operational
  - Global Hawk
  - BQM-34 Firebee
- Under development
  - Helios
- Concepts
  - Theseus B
  - Heliplat



Superpressure Airships

- Operational
  - None
- Under development
  - Sounder - SRI
  - Stratsat - ATG
- Concepts
  - Stratospheric LTA platform - Japan
  - High Altitude Airship - Lockheed+
  - High Altitude Long Endurance (HALE) airship- ESA

PLATFORM COMPARISON -1

Current Earth Science Platforms	Mission Duration	Science Instrument Capability, kg	Typical Altitude, km	In Situ Measurements (20-35 km)	Power to Instruments, W	Payload Recovery at End of Flight
Polar Sun Sync. Satellites	10 years	200-800	800	No	200-1000	No
Moderate Incl. Satellites	10 years	200-800	500	No	200-1000	No
Stratospheric Balloons	3-10 days	2000	35	Yes at float altitude	600-1000	Mostly
Stratospheric Balloons - Polar	10-33 days	1000	35	Yes at float altitude	600	Mostly
IR Balloons	20-70 days	10-50	17-28	Yes over oscillation range	50	No
Stratospheric Aircraft	<1 day	860-1650	20	No	1300-7000	Yes (Piloted) Mostly (UAV)
Radio/Drop Sondes	*2 hours*	*0.1*	*Radio to ~30 Drop from 20*	*Yes to ~30 (Radiosondes)*	*0.05*	*No*
Revolutionary Earth Science Platform	100 days to 1 year	200 or more	30-35	Yes	1000	Yes

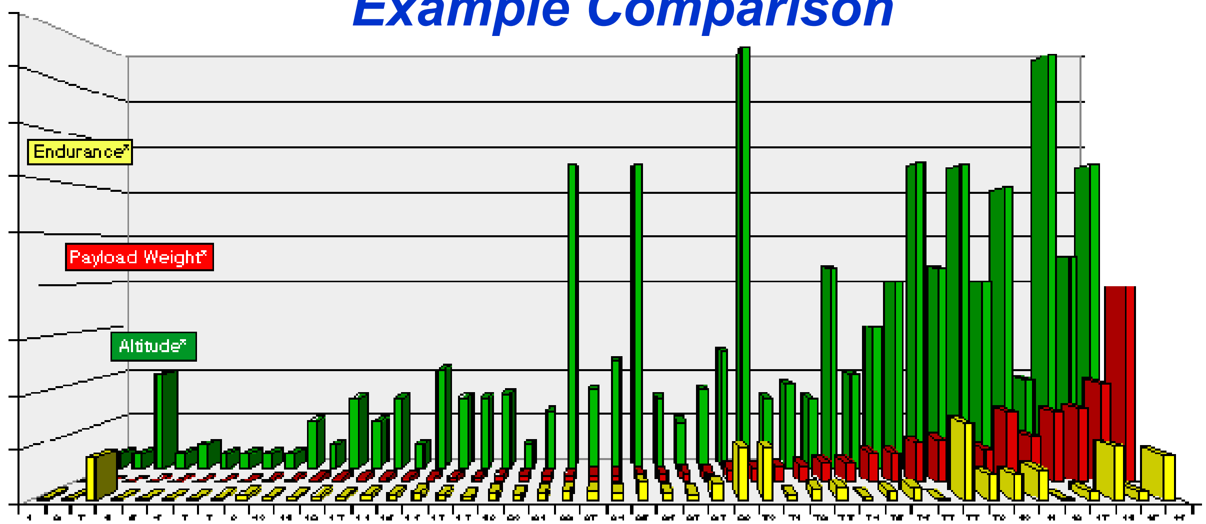
PLATFORM COMPARISON -2

Current Earth Science Platforms	Coverage	Site Coverage Duration	Diurnal Coverage	Surface Speed, m/s	"Air" Speed, m/s	Vertical Coverage	Resolution of Vertical Profiling	Surface Resolution (1° FOV), km	Signal-to-Noise Ratio
Polar Sun Sync. Satellites	Global	minutes	Two times of day	7,452	7,466	TOA to Surface	1-5 km	14.0	Low
Moderate Incl. Satellites	No polar	minutes	Day and night	7,613	7,627	TOA to Surface	1-5 km	8.7	Low
Stratospheric Balloons	Regional	hours	Day and night	0-50	<0.01	TOA to Surface	0.1 to 1 km	0.6	High
Stratospheric Balloons - Polar	Regional	hours	Day only	0-50	<0.01	TOA to Surface	0.1 to 1 km	0.6	High
IR Balloons	Regional	hours	Day and night	0-50	<0.01	20 km to Surface	0.1 to 1 km	0.3-0.5	High
Stratospheric Aircraft	Specific Site to Regional	Up to 24 hours	Day and/or night	0-200	15-180	20 km to Surface	0.1 to 1 km	0.3	High
Radio/Drop Sondes	*Specific Site*	*2 hours*	*Day and/or night*	*0-50*	*3-5 vertical*	*Surface to 20 km*	*0.01 km*	*N/A*	*High*
Revolutionary Earth Science Platform	??	??	??	??	??	??	??	??	??

Platform Evaluation Criteria - 1

- **Meets science requirements**
- **Payload capability**
  - Size or performance
  - Altitude
  - Duration
  - Range
  - Speed
  - Power availability

Example Comparison



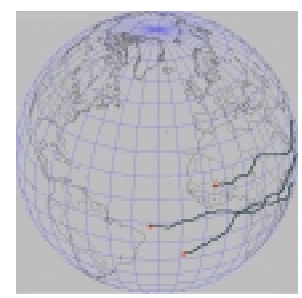
- **Gross platform size and mass**
  - Larger systems carry more payload and cost more
- **In situ measurement ability**
  - Too slow or too fast
  - Vertical velocity

Platform Evaluation Criteria - 2

- **Launch, operations and payload recovery**
  - Launch complexity
  - Weather and seasonal limitations
  - Solar illumination
  - Facilities needs
  - Air traffic control limitations
  - International overflight
  - Human, property and payload safety requirements
  - Landing site geography



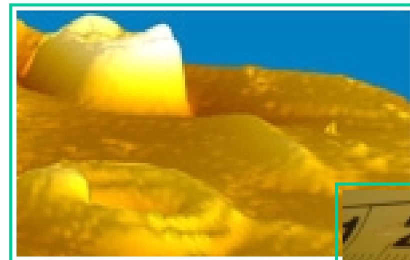




- **Flight path control**
  - Position and attitude control requirements
  - Seasonal and latitudinal wind effects e.g. station-keeping
  - Formation and network control ability

Platform Evaluation Criteria - 3

- **Reliability**
- **Airborne life-limiting factors**
  - UV degradation of materials
  - Consumables
  - Hardware failure
- **Life-cycle costs**
  - Platform research, development and testing
  - Recurring and replacement
  - Operations and disposal



Potential Platform Development Challenges

- Long-duration flight in stratospheric environment
- Platform flight path control
- Launch location and launch time flexibility
- Reliable operation and payload recovery
- Precise orientation and pointing knowledge
- Payload power
- Low life-cycle cost

Summary

- Potential candidate stratospheric platforms are being identified
- No current platform has all stated capabilities of revolutionary stratospheric platform
- Pathways exist and development is ongoing for several platforms that could have the potential to meet stated capabilities
- Criteria for evaluation of platform options are being developed
- The ability to meet Earth science requirements will be a key element of the planned platform evaluation
- Platform development challenges identified

Appendix C: Data Capture Questionnaire

Data Capture Questionnaire

Presentation to
RASC Stratospheric Platform Earth Science Workshop

By Dr. Alexey A. Pankine
Global Aerospace Corporation
http://www.gaerospace.com/

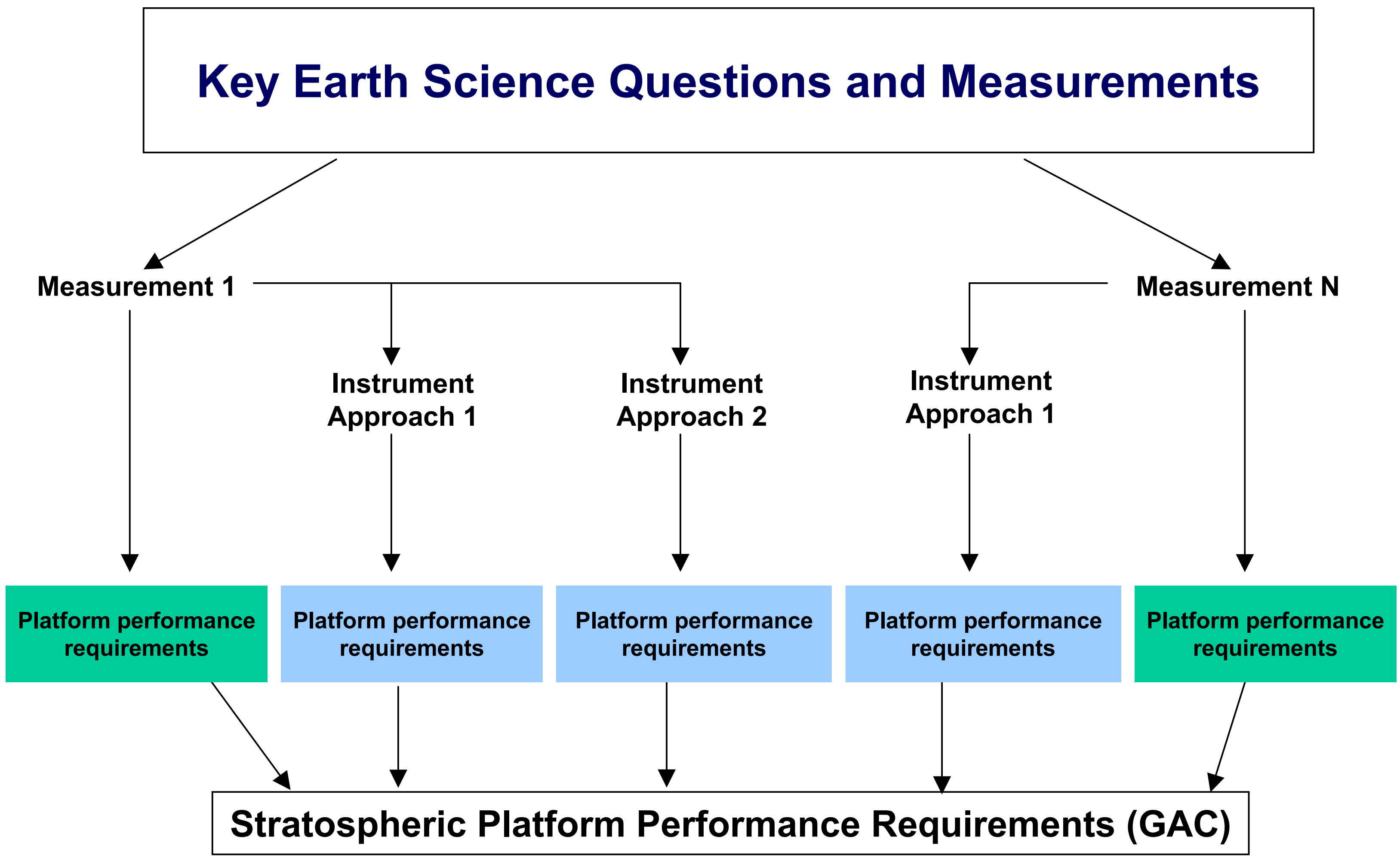
19 June 2002

Global Aerospace Corporation

Introduction

- Future technology development needs to be driven by scientific requirements.
- For the rest of the day we will work in groups on science requirements that define desired stratospheric platform performance.
- Questionnaire helps guide your input.

Platform Requirements Flow



Sample Questionnaire, p.1

Group: **Atmospheric Chemistry** Initials______**AAP**_________________

Use the following table to briefly describe the measurements needed to answer key science questions. …

Key Science Questions	What measurements are needed to answer these questions?
How is stratospheric ozone changing, as the abundance of ozone-destroying chemicals decreases and new substitutes increases?	**Ozone profiles in tropics from the troposphere up to 35 km**
Other science questions can be listed here	

For each measurement create a Measurement Requirements (green) page.

Sample Questionnaire, p.2

Required Measurement:____ozone profiles________________________

Table 1. Platform performance requirements dictated by the Required Measurement:

Spatial characteristics of the measurement:	
Desired horizontal coverage	**Tropics, between 15N and 15 S**
Desired horizontal resolution within the coverage region	**5° latitude, 3° longitude**
Desired vertical coverage	**From troposphere to 35 km**
Desired vertical resolution	**100 m**
Spatial accuracy	**1°**

Sample Questionnaire, p.2 (cont.)

Temporal characteristics of the measurement:	
Flight duration	**2 month**
Frequency of observations during the flight	**Every 2 hours day and night**
Simultaneity with other observations	**All platforms make simultaneous observations**
Other:	

For each Required Measurement page create one (or several) Instrument Approach (blue) page(s).

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Sample Questionnaire, p.3

Instrument Approach:_____Limb scanning instrument_____________

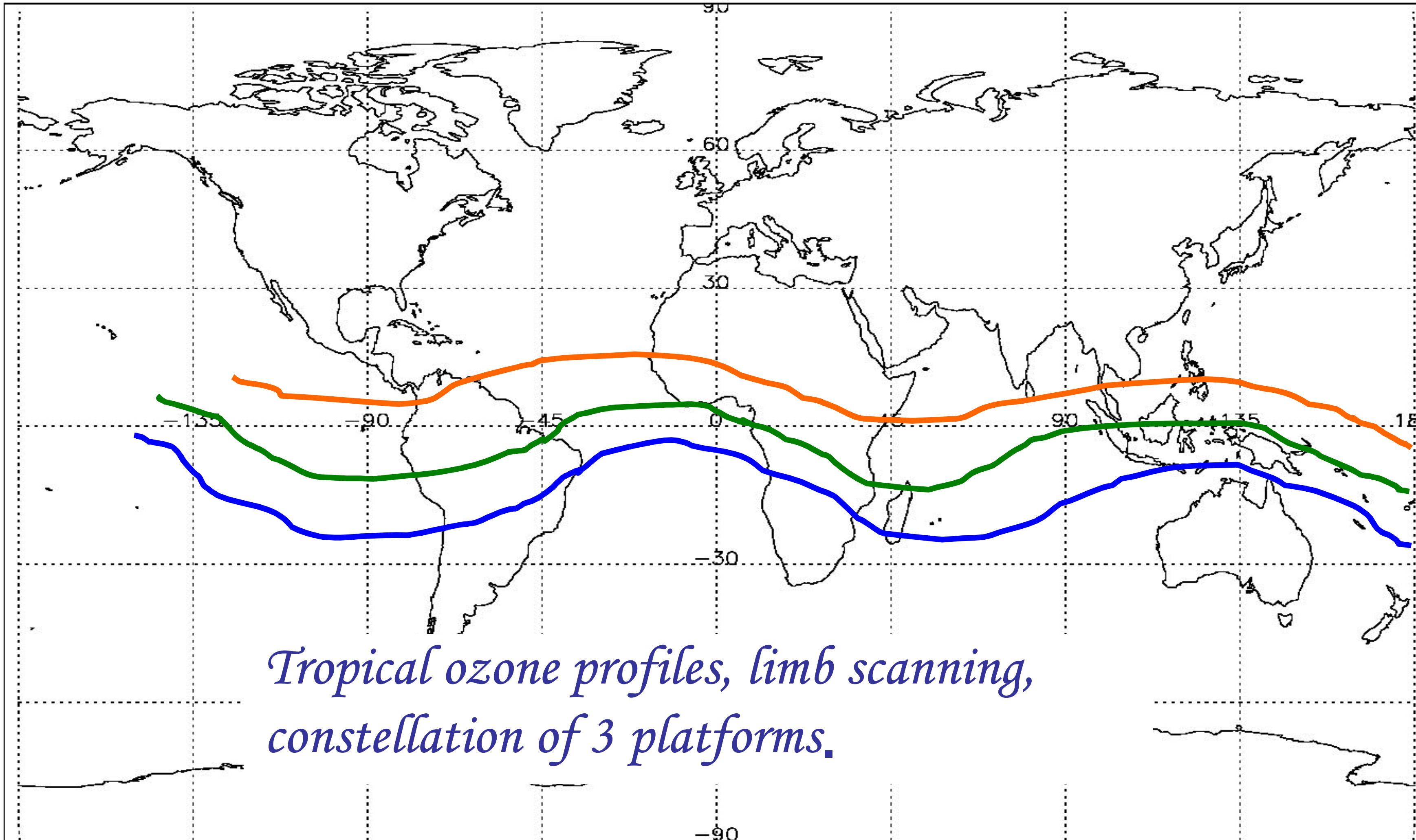
Table 1. Platform performance requirements dictated by the Instrument Approach:(consider both current and future – next 30 years – instruments):

Safe payload recovery	**Crucial (expensive instrument)**
Useful science payload mass	**At least 200 kg**
Power draw (include temporal profile if possible)	**100 W continuous**
Pointing accuracy, including: Platform attitude control; Platform attitude knowledge.	**Attitude knowledge within 1° for instrument pointing**
Position accuracy, including: Platform position control; Platform position knowledge.	**Position knowledge within 1 km**

Sample Questionnaire, p.3 (cont.)

Calibration (In flight, via ground truth, pre/post flight)	**In flight, every 10 days**
Data storage and relay	**10 Mbytes/day storage**
Coordination between platforms	**2 platforms make remote measurements of the same atmospheric region**
Other	

Sample Questionnaire, p.4



Tropical ozone profiles, limb scanning, constellation of 3 platforms.

Breakout Groups

Atmospheric Chemistry

Dr. William S. Heaps, Chair
Prof. William H. Brune
Dr. Elliot Weinstock
Dr. Randy Kawa
Dr. Arlyn Andrews

Geomagnetism

Dr. Michael Purucker, Chair
Dr. Yury Tsvetkov
Dr. Jim Heirtzler
Dr. Gunther Kletetschka
Dr. Patrick T. Taylor
Dr. Dimitar Ouzounov
Dr. Jeff Love

Earth Radiation Balance

Prof. Zhanqing Li, Chair
Dr. Albert Arking, Co-Chair
Dr. Wenying Su
Dr. Ellsworth G. Dutton
Prof. Rachel Pinker
Dr. Seiji Kato
Dr. Dave Atlas
Dr. Jay Herman
Dr. Lee Harrison
Prof. Thomas Vonder Haar

Appendix D: Key Questions Outlined in NASA's Earth Science Enterprise (ESE) Strategic Plan

The mission of NASA's Earth Science Enterprise (ESE) is to develop a scientific understanding of the Earth system and its response to natural or human-induced changes to enable improved prediction capability for climate, weather, and natural hazards. In short the ESE is devoted to answer the following question:

"How is the Earth changing and what are the consequences of life on Earth?"

The scientific strategy to answer this immensely complex question is laid out in five steps:

1) How is the global earth system changing?

   - How are global precipitation, evaporation, and the cycling of water changing
   - How is the global ocean circulation varying on interannual, decadal, and longer time scales?
   - How are global ecosystems changing?
   - How is stratospheric ozone changing, as the abundance of ozone-destroying chemicals decreases and new substitutes increases?
   - What changes are occurring in the mass of the earth's ice cover?
   - What are the motions of the earth and the earth's interior, and what information can be inferred about earth's internal processes

2) What are the primary causes of the earth system variability?

   - What trends in atmospheric constituents and solar radiation are driving global climate?
   - What changes are occurring in global land cover and land use, and what are their causes?
   - How is the earth's surface being transformed and how can such information be used to predict future changes?

3) How does the earth system respond to natural and human-induced changes?

   - What are the effects of clouds and surface hydrologic processes on earth's climate?
   - How do ecosystems respond to and affect global environmental change and the carbon cycle?

- How can climate variations induce changes in the global ocean circulation?

- How do stratospheric trace constituents respond to change in climate and atmospheric composition?

- How is global sea level affected by climate change?

- What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?

4) What are the consequences of change in the earth system for human civilization?

   - How are variations in local weather, precipitation and water resources related to global climate variation?

   - What are the consequences of land cover and land use change for the sustainability of ecosystems and economic productivity?

   - What are the consequences of climate and sea level changes and increased human activities on coastal regions?

5) How well can we predict future changes in the earth system?

   - How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?

   - How well can transient climate variations be understood and predicted?

   - How well can long-term climate trends be assessed or predicted?

   - How well can future atmospheric chemical impacts on ozone and climate be predicted?

   - How well can cycling of carbon through the earth system be modeled, and how reliable are predictions of future atmospheric concentrations of carbon dioxide and methane by these models?

(http://www.earth.nasa.gov/science/index.html)

Appendix E: Data Capture Questionnaires as Filled Out by the Science Group